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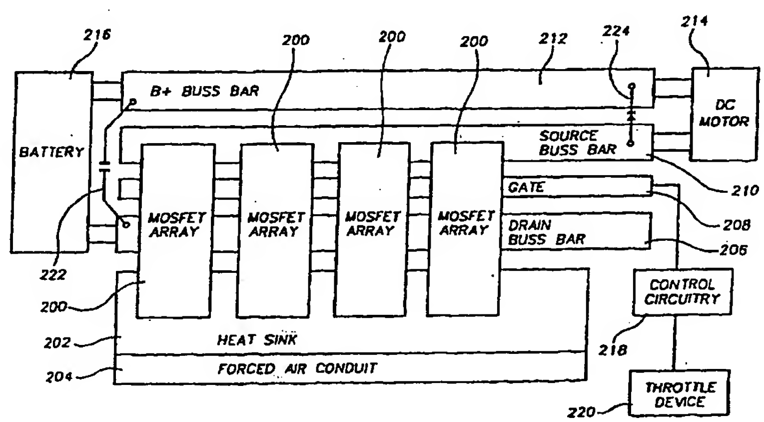

(57) Abstract

A solid state power controller has features which improve efficiency and reliability. In one aspect, a plurality of power transistors (200) are arranged in parallel such that at least one type of lead (source, gate and drain) is electrically coupled to a current carrying bar (212). Preferred embodiments have two or all three types of leads electrically coupled to different current carrying bars, and especially preferred embodiments have one more of the source, gate and drain types of leads directly connected to the respective current carrying bar. In other aspects, the transistors comprise MOSFETs driven by a duty cycle modulator producing pulses at a frequency of at least 19,600 Hz. It is also provided that the power controller can be embodied in an electric vehicle, and that a significant power source for the power controller will be a battery (216). In another aspect, the circuit platform structure may include a battery voltage bus bar for direct connection of a battery voltage to a DC motor circuit, and a free-wheeling rectifier assembly connected across the DC motor between the battery voltage bus bar and the source bus bar of the device. An array of storage/filtering capacitors may also be positioned across the battery between the battery voltage bus bar and the drain bus bar of the device.

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TITLE

IMPROVED MOTOR CONTROL CIRCUITRY AND CIRCUITRY ENCLOSURE

BACKGROUND OF THE INVENTION

1. FIELD OF THE INVENTION

This invention relates generally to electric motor control circuitry, circuitry platforms and circuitry enclosures. The invention relates more specifically to the control of a DC electric motor whose speed is determined by the operation of a throttle, wherein less than full discharge of a direct current power source through the motor is required and for which high currents and high temperature operating environments are anticipated. Most frequently, this invention will find application in the control of DC electric motors associated with battery-powered vehicles.

2. DESCRIPTION OF THE RELATED ART

Efforts to get away from a reliance on fossil fuels have lead to increased usage of electrically propelled engines and motors, especially as they might apply in manned or unmanned vehicles. One of the most significant problems associated with the widespread use of such electrical vehicles is the necessity of maintaining a sufficient direct current electric power supply for long term use of the vehicles. New battery technologies have reduced the size and weight of direct current power storage devices, but have not altogether addressed the problems of frequent recharging of the batteries. Efficient use of the stored power in such vehicles is therefore of great concern.

Efficiency in the use of electrically driven motors is primarily a matter of regulating the power drain from a direct current power source in a manner that utilizes only such power as is required by the engine or motor for the speed selected. In the past, electric motor controller circuits were designed to tap the direct current power source for a maximum flow of current based upon the highest expected motor speed that might be required, and to drain any excess current off through some other load when the motor did not require such a high level of current. In most cases this drain of the excess, unneeded current or voltage potential resulted in the waste of such power and a resultant decrease in the efficient use of the power source.

Early types of electric motor controllers typically utilized groups of resistive loads to provide alternate current drains on the power source. These resistive loads could be placed in

parallel or in series with the electric motor and switched in and out depending upon the current requirements of the motor. It is well known, however, that such resistive loads drain significant current from a battery and dissipate such energy in the form of heat. These approaches, therefore, do little for the efficiency of the motor or the vehicle it propels.

Efforts have been made in the past to regulate current flow from a direct current power source through an electric motor in a manner that does not simply channel the current into another load. Such efforts have focused on the use of solid state switching devices to pulse the current through an electric motor in a manner that effectively opens and closes a circuit between the power source and the primary load (the electric motor) at a specific frequency. The pulse durations or pulse widths are directly related to the desired speed of the motor. The greater the speed, the longer the duration of the current pulses in which the current flow through the motor is in a full on condition. The lower the desired speed, the longer the current pulses in which the flow of current is in an off condition. The current through the motor is always either in a full on or a full off condition with the ratio of on duration to off duration determining motor speed. Use of such solid state switching devices as silicone control rectifiers (SCRs) and metal oxide semiconductor field effect transistors (MOSFETs) have shown great promise in these applications.

Circuits that utilize SCR and MOSFET devices, however, are only as efficient as their ability to translate some throttle indication of a desired motor speed to an appropriate current flow and their ability to handle the pulsed frequencies used to control the motor. This efficiency includes the ability to instill circuit reliability and overall motor and vehicle safety while achieving a longer recharge cycle. This efficiency also includes the ability of such circuits and switching devices to function continuously in high temperature environments. Past attempts to utilize such solid state circuit devices as SCRs and MOSFETs have not only suffered from reliability and ruggedness problems, but have also suffered from a complexity and expense not merited by the motors and devices that are intended to be controlled by the circuits. In other words, past attempts to accomplish the regulated control of current through a DC electric motor have succeeded, but only at the expense of unusual complexity, poor thermal performance and the associated lack of reliability and versatility that follows.

Solid state current switching devices in applications of concern here, are typically controlled (gated) by a square wave signal having variant pulse widths. This gating square wave is typically generated by a pulse width modulator that translates a given voltage (or resistance or current) level into a related pulse width in the square wave signal. The voltage level itself,

and therefore the pulse width of the square wave, is designed to be representative of a throttle or controller position for the motor or motor driven vehicle.

While basic pulse width modulation technology, as is briefly described above, may be well known in the field of controlling DC electric motors, very little has been done to instill this technology with circuit designs, circuit platforms, and circuit enclosures that provide the efficiency, features, function, recovery time, and thermal characteristics desired by industries that utilize such DC motors. Many of these desired features and functions of such circuits and circuit enclosures have been identified in the industry, and to some extent they have been addressed, but only in association with other types of engines and propulsion systems. Because of the fundamental differences between internal combustion engines and electric motors, very few of the controller systems associated with the former can be implemented with the latter.

It would therefore be advantageous to have a motor vehicle controller circuit, circuit platform, and circuit enclosure that provides not only efficient operation of a DC electric motor, but also provides a reliable and rugged device.

SUMMARY OF THE INVENTION

The present invention provides a sold state power controller having features which improve efficiency and reliability. In one aspect, a plurality of power transistors are arranged in parallel such that at least one type of lead (source, gate and drain) is electrically coupled to a current carrying bar. Preferred embodiments have two or all three types of leads electrically coupled to different current carrying bars, and especially preferred embodiments have one more of the source, gate and drain types of leads directly connected to the respective current carrying bar. In other aspects, the transistors comprise MOSFETs driven by a duty cycle modulator producing pulses at a frequency of at least 19,600 Hz. It is especially contemplated that the power controller can be embodied in an electric vehicle, and that a significant power source for the power controller will be a battery. In still other aspects, the circuit platform structure may include a battery voltage buss bar for direct connection of a battery voltage to a DC motor circuit, and a free-wheeling rectifier assembly connected across the DC motor between the battery voltage buss bar and the drain buss bar of the device. An array of storage/filtering capacitors may also be positioned across the battery between the battery voltage buss bar and the source buss bar of the device.

It is, therefore, an object of this invention to provide embodiments having a reliable, efficient, and thermally stable means of regulating the discharge of a DC energy source, such as a battery, through a DC load, such as an electric motor. A further and related object of this invention is to provide a reliable, efficient, and thermally stable, means of regulating the speed/torque of a DC electric motor and/or the speed/acceleration of a vehicle powered by such a motor.

It is another object of the present invention to provide embodiments having circuitry that isolates the direct current power source from all power drain significant destinations in the circuit or in the vehicle, under conditions where an electric motor and/or vehicle are placed in an "off" condition.

It is another object of the present invention to provide embodiments having electric motor controller circuitry operable in conjunction with different types of throttle position circuits that is versatile in its adaptability to a number of vehicular requirements and DC motor configurations.

It is a further object of the present invention to provide embodiments having electric motor controller circuitry operable in conjunction with throttle position circuitry that is highly immune to voltage, temperature and other irregularities and extremes from conditions both internal and external to the circuitry and circuitry enclosure.

It is a further object of the present invention to provide embodiments having an electric motor control circuitry platform and enclosure structure that minimizes temperature sensitive current paths, reduces resistive heat sources within the circuit, and further dissipates any remaining heat through the use of efficient thermal masses.

In fulfillment of these and other objects, a particularly preferred embodiment provides a solid state, electric motor control circuit operable in conjunction with a variety of throttle devices that incorporates; a vehicle operation inhibit circuit, a pulse width modulation circuit, an inverting MOSFET driver circuit, a plurality of power MOSFET devices, a voltage regulator circuit, and a current delivery circuit associated with an external DC electric motor. These circuit elements combine to translate a mechanical throttle position into a voltage, current, or resistance level signal that can be converted by pulse width modulation circuitry into a pulsed wave form signal that suitably drives an array of MOSFET solid state switches, so as to control the flow of current through a DC electric motor. The circuit utilizes a plurality of parallel MOSFET devices whose gates are regulated by the pulse width modulated signal and which share the load of the external DC motor. The circuit isolates the DC power source

from the power drain components in the circuit. The circuitry incorporates internal elements that raise the reliability of the overall circuit while still providing versatility in application. While the present circuitry involves voltage regulation components, it also involves under-voltage as well as over-voltage protection and significant levels of signal filtering. The circuit platform provides an efficient heat sink/thermal mass configuration to handle the heat generated by the high speed switching devices and a current path structure that minimizes the high current portion of the circuitry. The circuit structure reduces the number of high current junctions and eliminates many of the normally fusible links in such controller circuitry. Switch drivers are utilized within the circuit to prevent unintentional activation of the high current switches. In specific high current high temperature environments, the platform and enclosure of the present invention provides an efficient forced air cooling structure to further increase the reliability and efficiency of the device.

Other objects and advantages over the prior art will be apparent to those skilled in the art upon a reading of the detailed description that follows together with the drawings described below.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a perspective view of the structural configuration of the motor control circuitry, circuitry platforms, and circuitry enclosure of a first preferred embodiment of the present invention.

FIG. 2A is a perspective view of a partial assembly of the motor control circuitry of the embodiment of the present invention shown in Fig. 1, disclosing the arrangement and structure of the current carrying buss bars.

FIG. 2B is a side elevational view of the motor control circuitry of the present invention shown in Fig. 1 .

FIG. 2C is an elevational side view of the motor control circuitry of the present invention shown in Fig. 1 .

FIG. 3A is a perspective view of the source buss bar of the circuitry shown in Fig. 1.

FIG. 3B is a perspective view of the ground buss bar of the circuitry shown in Fig. 1.

FIG. 3C is a perspective view of the B- buss bar of the circuitry shown in Fig.

FIG. 4 is an exploded perspective view of the housing and top plate assembly of the first preferred embodiment of the present invention.

FIG. 5 is a perspective view of the assembled motor controller of Fig. 1 .

FIG. 6 is an electronic schematic diagram showing the circuitry of the motor controller of the first preferred embodiment of the present invention.

FIG. 7 is a schematic block diagram of the primary structural and functional components of the generic motor controller of the present invention.

FIG. 8 is an exploded perspective view of a second preferred embodiment of the motor controller device of the present invention.

FIG. 9 is a detailed perspective of the heat sink - MOSFET mounting structure of the second preferred embodiment of the present invention.

FIG. 10 is a detailed top view of the heat sink - MOSFET mounting structure of the second preferred embodiment of the present invention.

FIG. 11 is an exploded perspective view of the forced air conduit cooling structure of the second preferred embodiment of the present invention.

FIGS. 12 and 12B are electronic schematic diagrams showing the circuitry of the motor controller of the second preferred embodiment of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Reference is first made to Figs. 1, 2A, 2B, and 2C for a general description of the structural arrangement of the electronic components of a first preferred embodiment of the motor controller circuitry of the present invention. Fig. 1 is a perspective view of the assembled motor controller circuitry shown with the enclosing housing and top plate removed. The device shown in Figs. 1 through 6 is appropriate for use in lower voltage (364) applications even though the basic structural and functional features of the device are common to higher voltage (144v) applications.

The motor controller circuitry assembly (10) of the present invention is constructed on base plate (12). Most of the discrete electronic components of the present invention are incorporated onto circuit control board (14), shown only generally in Fig. 1 . Circuit board (14) is connected in a mariner described in more detail below to three buss bars (16), (18), and (20). Buss bar (16), hereinafter referred to as the source or "S1" buss bar (16), provides one side of the DC voltage appropriate for powering a DC series motor. Buss bar (18), hereinafter referred to as "ground" buss bar (18), provides the primary ground connection between the motor and battery circuit through the control circuitry of the present invention. Buss bar (20), hereinafter referred

to as "B +" buss bar (20), provides the positive DC battery voltage for the series motor associated with the present invention.

Among the large scale electronic components associated with the circuitry of the present invention, are capacitors (22a) and (22b) which, in the preferred embodiment of the present invention, are 10,000 microfarad capacitors (Cornell Dubilier Part No. 139R732M055AC213). Capacitor (22a) is connected between B+ buss bar (20) at B+ buss bar arm (36) and ground buss bar (18). Likewise, capacitor (22b) is connected between B + buss bar (20) at B + buss bar arm (34) and ground buss bar (18). B + buss bar (20) is held in a position separate from S1 buss bar (16) by diode (24) (International Rectifier Part No. 1R4O3NQ1OO) as shown in more detail with respect to Figs. 2B and 2C. In addition, B + buss bar (20) is separated and electrically insulated from base plate (12) by way of buss bar insulator (28).

Diode (24), B+ buss bar (20) and buss bar insulator (28) are attached to base plate (12) at leg (26) of diode (24) through hole (30). A similar attachment configuration is positioned at an opposite end of diode (24), though hidden in the perspective view shown in Fig. 1.

S1 buss bar (16) is attached to the above-described assembly through apertures not shown in Fig. 1 and is attached by way of bolts (32). Ground buss bar (18) is secured to this assembly by way of the ground set of connecting contact screws (44) (partially hidden in Fig. 1 by capacitor (22b)) as described in more detail below, as well as its attachment to capacitors (22a) and (22b). Across the attachment points described above for capacitors (22a) and (22b) are surge suppressors (38a) and (38b) (General Instruments Part No. 5KP40A). The function of surge suppressors (38a) and (38b) is described in more detail below in conjunction with Fig. 6. Attachment of surge suppressors (38a) and (38b) to the connections for capacitors (22a) and (22b) is made by way of terminal posts (40) and connectors (41).

S1 buss bar (16) extends through S1 buss bar leg (42) to an area beneath circuitry board (14) and is attached thereto through the MOSFET devices (hidden in Fig. 1) described in more detail below by way of the source set of contact terminals (44). Associated with ground buss bar (18) and S1 buss bar (16) is snubber assembly (47) which is comprised of resistor (48) (10 ohm, 5%) and capacitor (50) (0.1 microfarad). Attachment to the circuit is by way of terminal points (46) on S1 buss bar (16) and an additional terminal point on ground buss bar (18) not shown.

Reference is now made to Fig. 2A for a more detailed description of the buss bar assemblies of the present invention and the basis for the improved conduction of the power currents associated with the motor controller of the present invention. One objective of the

present invention is to provide significantly low resistance current paths through the switching devices for the primary motor currents associated with the driving motor of the present invention. In other words, the objective is to shorten the current path between the batteries that provide the current source and the motor which provides the current load. The objective of the present invention is to control this current flow through an array of MOSFET devices in the most efficient and power conservative manner possible. To achieve this goal, the present invention utilizes an array of optimally configured buss bars that connect the battery power source with the motor current load through the optimally positioned MOSFET devices in a thermally efficient structure and enclosure.

The arrangement of buss bars, therefore, shown in Fig. 2A serves the purpose of arranging each of the large scale electronic components of the circuitry of the present invention in a highly efficient manner and, at the same time, provides the shortest current path between the battery power and the load connections with the fewest number of junction points, especially as between the high current components of the system.

Once again, the buss bars of the present invention are shown as they are positioned on base plate (12). In Fig. 2A, all other components associated with the circuitry are removed for clarity and for a better description of the arrangement and functions of the buss bars.

Specifically, S1 buss bar (16) is shown to incorporate leg (13) and leg (15) positioned generally at right angles to each other. Leg (13) serves the purpose of securely mounting the buss bar atop diode (24), not shown in Fig. 2A. Leg (15) serves eto make the necessary connections to the MOSFET devices (33), not shown in Fig. 2A. Connections on leg (15) are made by way of connection pads (52) spaced apart by cutouts (54). In the preferred embodiment, there are three such connection pads (52) appropriate for attachment to MOSFET devices (33) described in more detail below.

Ground buss bar (18) retains a single leg (17) by way of angle section (23). Like leg (15) of buss bar (16), leg (17) of buss bar (18) retains a plurality of connection pads (56) interspaced by cut-outs (58). Connections of the drain terminals of the MOSFET devices (33) to the ground buss bar (18) by way of connection pads (56) is described in more detail below. In addition, ground buss bar (18) is connected to capacitors and surge suppressors as described above, at the terminal points on an upright section of ground buss bar (18).

B+ buss bar (20) is comprised of major leg (19), which, as described above, is directly mounted to base plate (12) through insulator (28). Main leg (19) retains two secondary uprights in the preferred embodiment already identified with respect to Fig. 1 as uprights (34)

and (36). Uprights (34) and (36) have terminal points (60) which provide attachment points for the capacitors and surge suppressors as described above.

Reference is now made to Figs 2B and 2C for further views of the completed internal assembly of the first preferred embodiment of the present invention.

Fig . 2B is an end view of the assembly shown in Fig . 1, disclosing with more clarity the arrangement of buss bars (16), (18) and (20) and their terminal connections to capacitors (22a) and (22b). Hidden in Fig. 2B, for the most part, is circuit board (14).

Again, B + buss bar (20) is shown as it is positioned atop base plate (12) and mounted thereto by way of legs (26) of diode (24) as described above. Upright sections (34) and (36) of buss bar (20) are also shown in profile in Fig. 2B Diode (24) positions buss bar (16) atop buss bar (20) at a spaced distance. Bolts (32) secure buss bar (16) through diode (24) through buss bar (20) to base plate (12). Appropriate bushings are utilized to insulate bolts (32) Surge suppressors (38a) and (38b) are shown as they are connected to terminal points (40) by way of connectors (41), thereby bridging capacitors (22a) and (22b) between B + buss bar (29) and ground buss bar (18). Ground buss bar (18) is shown as it is angled (18a) above S1 buss bar (16), without making contact to S1 buss bar (16) or to bolts (32), which connect S1 buss bar (16) to diode (24) and B+ buss bar (20) to base plate (12).

Reference is now made to Fig. 2C for a side view of the assembly shown in Fig. 1, better disclosing the position of circuit board (14), MOSFET devices (33) and the associated buss bar connections thereto. S1 buss bar (16) is shown as its primary leg (15) extends out from it. diode (24) is shown positioning S1 buss bar (16) above B+ buss bar (20). Leg (26) of diode (24) is shown at one end. Again, surge suppressor (38b) is shown attached to terminal point (40) by way of connector (41). Capacitor (22b) is shown in its position connected to the same terminal (40). Ground buss bar (18) is only partially seen in Fig. 2C, where it angles around S1 buss bar (16) to a position parallel with S1 buss bar (16) as shown in Fig. 2A.

Circuit board (14) is shown from the side in Fig. 2C as are connecting terminals (44) therethrough of which three connect to ground buss bar (18) and three connect to the MOSFET gates.

Reference is now made to Figs. 3A, 3B and 3C for a more detailed description of the specific structural configurations for buss bars associated with the circuitry of the present invention. Fig. 3A discloses S1 buss bar (16) showing its three primary legs. Support leg (13) is, as mentioned above, primarily for the purpose of structurally adhering buss bar (16) to base plate (12) by way of apertures (51). Electrical connections are made from the MOSFET

source terminals to S1 buss bar (16) by way of primary leg (15), which as described above, incorporates three connector pads (52) interspaced by cut-outs (54). In the preferred embodiment, a slight rise in buss bar (16) occurs between primary leg (15) and the combination of structural support leg (13) and upright connector (16a). This slight change in structural plane accommodates the positioning of the buss bar in conjunction with diode (24) and B+ buss bar (20).

Fig. 3B discloses in more detail the structure and function of ground buss bar (18). Buss bar (18) is comprised of two primary sections, upright section (18a) and primary leg (17). Upright section (18a) and primary leg (17) are connected through a double-angled section (23), designed to appropriately position upright section (18a) to receive capacitors (22a) and (22b) as well as provide terminal point (27) for the exterior ground connection, and terminal points (29) and (31) for surge suppressors (38 a) and (38b) as described above. Like S1 buss bar (16), ground buss bar (18) incorporates on its primary leg (17) three connector pads (56) interspersed by cut-outs (58), positioned so as to attach to the drain terminals located on MOSFET devices, not shown. Connection points (55) in Fig. 3A and (59) in FIG. 3B provide for the attachment ofOsnubber assembly (47).

Reference is now made to Fig. 3C for a detailed description of the B + buss bar (20) of the present invention. B+ buss bar (20) has three electrical connections, one external connector (25) located at the end of B + buss bar (20) and two additional connection points (60a) and (60b) located at the end of arms (34) and (36). Arms (34) and (36) extend upward from leg (19) of B+ buss bar (20). At each end of leg (19) are mounting apertures (30a) and (30b).

Reference is now made to Fig. 4 for a brief description of the enclosing structures for the first preferred embodiment of the present invention. Fig. 4 discloses an extruded housing (80) that surrounds and attaches to base plate (12) (not shown) in a manner that encloses the circuitry of the present invention on all but an upper face. Housing (80) is configured in a heat sink fin structure (84) to facilitate the removal of heat from base plate (12) and from the circuitry contained within. Housing (80) also retains four connector screw channels (86), one on each of the four corners of housing (80) in a mariner that permits attachment of housing (80) to base plate (12).

Attached to the top of housing (80) is a top plate (82) with similarly configured apertures (90) for the reception of screws for attachment to housing (80) and therethrough to base plate (12). Top plate (82) also retains four additional apertures (92, 94, 96, and 98) in the preferred embodiment, three (92, 94, and 96) for the appropriate reception of the external terminal

connectors and a fourth (98) for the reception of a quick-connect jack for attachment to the throttle circuit/mechanism to be used in conjunction with the present invention.

Reference is now made to Fig. 5 for a perspective view of the assembled apparatus of the present invention. Here, housing (80) is shown with top plate (82) attached and as connected to base plate (12) by way of four threaded screws (102), one at each corner. Protruding through top plate (82) are shown the external connectors from the B + buss bar (20), the ground buss bar (18) and the S1 buss bar (16). Surrounding each of these connectors is an appropriately configured grommet (100). Also shown protruding through top plate (82) is quick-connect jack (104) appropriate for reception of a cable from the throttle mechanism for use in conjunction with the present invention.

After attachment to base plate (12), it is seen from Fig. 5 that apertures (106) remain accessible for attachment of base plate (12), and thus the entire assembly, to a surface on which the apparatus of the present invention is to be mounted. The surface mount feature is important in further assisting in the heat dissipation objective of the present invention.

Reference is now made to Fig. 6, which discloses an electronic schematic diagram showing the basic electronic circuitry associated with the apparatus of the present invention. Essentially, the circuitry described in Fig. 6 duplicates that described in applicant's co-pending patent application, entitled "Electric Throttle and Motor Control Circuitry" , and referenced above. The connectors described in the above sections related to the structural packaging for the circuitry include 31 (associated with connector (104) in Fig. 5), E1-E6 (associated with connectors (44) in Figs. 1, 2B and 2C), as well as the grounding terminal shown in a plurality of locations in Fig. 6.

Reference is now made to Fig. 6 for a more detailed description of the control circuit of the present invention. Matching an appropriate throttle connector (for example connector (104) in Fig. 5, input connector (J1) in Fig. 6 provides the arrangement and assignment of pins for appropriate communication of voltages and throttle position signals to the circuitry. Input connector (J1) incorporates circuit voltage output (110), which provides the approximate +12 volts DC (less voltage drops through resistor (121)) to ancillary circuit elements such as the throttle circuitry. Ground connection (iii) likewise communicates a common ground between the various vehicular circuits. Control voltage input connection (112) receives the variable voltage, current, or resistance output from the throttle device and conveys it to the appropriate circuitry in Fig. 6. DC power supply voltage input (113) receives and conveys battery voltage (+36 VDC to this embodiment) to voltage regulator circuit (116). And

finally, inhibit signal input (114) conveys a ground condition (when present) for inhibitor circuit (170) to the appropriate place in the circuitry described in Fig. 6. It should be noted that in the event that the connection at connector (J1) is broken or removed, input (114) will go high and inhibit the circuitry.

Reference is now made within Fig. 6 to voltage regulator circuit (116) and a detailed description of the elements that it comprises. The core of voltage regulator circuit (116) is regulator integrated circuit (117), which in the preferred embodiment is an LT317AT integrated circuit. Input voltage to regulator IC (117) is provided by way of noise suppression inductor (118) (0.5 microH) and resistor (119) (10 ohm, 3 watt). The output of voltage regulator (117) provides a +12 volts DC to a number of circuit elements of the present invention. By way of output resistor (121) (47 ohm), a voltage is provided back through connector (31) to the ancillary circuit elements of the vehicle. Filtering for this output voltage is provided by capacitor (127) (0.22 microfarad). A voltage is provided by way of resistor (122) (232 ohms), held up by resistor (126) (2.0 K) to provide the appropriate voltage at the adjustment input of regulator IC (117) and to also appropriately configure the output circuit voltage by way of short circuit protection diode (128) (1N914 in the preferred embodiment). These output voltages are appropriately filtered by capacitors (124) (10 microfarad), (125) (15 nanofarad), and (127) (0.22 microfarad). The output of voltage regulator circuit (116) is provided not only back to certain ancillary elements as described above, but also to the necessary circuit elements in Fig. 6, as described in more detail below.

The primary component of the circuitry described in Fig. 6 is pulse width modulation circuit (132). In the preferred embodiment, this PWM circuit is an integrated component typified by a SG2524BDW chip. The specifications for this integrated circuit, as well as various applications, are well known in the art and are published in association with the integrated circuit and are incorporated herein by reference.

The internal circuit elements of PWM circuit (132) that are of concern in the present application include a signal amplifier op amp, comparator, oscillator, PWM latch, PWM output circuit, +5 volt DC voltage reference, under voltage sensor, current limiter op amp, and inhibit shutdown switch circuit. The signal amplifier op amp of PWM circuit (132) receives the variable voltage signal from the throttle/vehicle sensor circuit by way of connection (112) on connector (31). Through resistors (134 and 135) (which total 69.9 K in the preferred embodiment and which may be replaced by a single resistor), this signal voltage is biased by resistor (136) (100 K) tied to ground. Appropriate biasing for the inverting amplifier in PWM

(132) is also provided by way of resistor (137) (200 K) to ground. Filtering for the input voltage signal is provided by way of capacitor (140) (330 picofarad). The output of the internal amplifier is conveyed to the internal comparator and is fed back to the amplifier by way of resistor (141) (69.1 K) biased by resistor (143) (49.9 K). The feedback loop is filtered by capacitor (142) (0.1 microfarad). Biasing provided by resistor (143) is assisted by pull up resistor (144) (49.9 K) which is connected to a reference +5 volt DC. This reference voltage is filtered by capacitor (145) to ground (330 picofarad). The other input of the internal comparator is received from the oscillator which provides a sawtooth wave of a specific frequency in order to effect the pulse width modulation of the variable voltage signal output by the amplifier. The internal oscillator is configured by way of external components, resistor (146) (19 K), capacitor (147) to ground (3.3 nanofarad), and capacitor (148) (0.22 microfarad). The combination of resistor (146) and capacitor (147) determine the oscillator frequency (20kHz $\pm$ 2% in the preferred embodiment). Capacitor (148) provides noise filtering for the +5 volts DC reference voltage. Resistor (146) is used to fine tune the oscillator frequency.

To complete the external components utilized to modify and control the operation of PWM IC (132), the current limiter op amp is configured with current limiter resistor (150) (270 K), filtering capacitor (151) (10 microfarad) to ground, bias resistor (152) (49.9 K), and parallels its output with the amplifier into the comparator. The operation of the current limiting feature of the present invention will be described in more detail below.

Operating voltage to IC (132) is provided from voltage regulator circuit (116) by way of +V supply resistor (160) (10 ohm). This supply voltage is filtered by way of filtering capacitor (161) to ground (0.68 microfarad). Pull up resistor (162) (1 K) is positioned appropriately with the output of PWM IC (132). PWM IC (132), as configured, senses low battery/DC power source conditions due to either large current or low battery charge conditions. In any case, the r output is gradually limited to zero by PWM IC (132) as battery voltage falls below 28 volts DC. The combination of resistor (150) and capacitor (151) also provide a 0.5 second turn on time when power is applied to the unit.

The internal comparator compares the sawtooth wave generated by the oscillator with the variable voltage generated by the amplifier and produces a pulse width modulated square wave signal to the internal PWM latch and from there through the PWM output circuit. The configuration of the output circuit in Fig. 6 shows an arguably redundant use of the standard internal components of the IC described in the preferred embodiment. Parallel outputs are

combined to create a single pulse width modulated signal to the balance of the circuitry. The PWM latch simply controls the operation and output of the comparator and prevents the uncontrolled cycling of the output signal. The function of the PWM latch can be modified by inhibiting the shutdown switch, a feature also utilizing internal circuitry in the IC of the preferred embodiment so as to terminate the output signal from PWM IC (132) when required.

As indicated above, parallel outputs from PWM circuitry (132) are combined external to the IC and are provided to invertor circuit (164). The output of PWM circuit (132) is actually inversely related to the MOSFET gate voltages required for the desired current flow in the DC motor. This square wave output, therefore, must be inverted prior to utilization by the MOSFET circuits which control the current to the motor. This square wave conversion is provided through invertor circuit (164) by way of invertor amplifier (165) (part of a Teledyne TS4429E0A IC in the preferred embodiment). IC (165) contains one op amp in inverting configuration to provide an output to the MOSFET circuit(s). Amplifier IC (165) receives operating voltage from voltage regulator circuit (116) and has the operating input filtered by way of capacitors (166) and (167) (0.68 microfarad and 2.2 microfarad respectively in the preferred embodiment). The inverted output from invertor circuit (164) is provided in parallel to a plurality of .MOSFET devices through connectors (168) (see connectors (44) in Fig. 1). The Power MOSFET gate is driven by the invertor circuit typically through a gate resistor (10 ohm, not shown). The damping of MOSFET device is controlled by a MOSFET resistor (10 ohm, 5 watt) and MOSFET capacitor (0.1 microfarad) (see snubber assembly (47) in Fig.(1). Reverse induced current flow through the DC motor is shunted by a flyback diode (or diodes). Reverse induced energy is stored by way of the previously described capacitor (10,000 microfarad in the preferred embodiment, +36 volts to ground) as well as in the battery and, as indicated above, forward current to the motor by a direct connection through the MOSFET network from DC power supply (+36 volt battery) to DC motor (260) is arranged.

Ancillary to the above described circuitry in Fig. 6 are a number of additional circuit components that convey the inhibit signal described above to the appropriate shutdown circuit within pulse width modulation IC (132). Inhibit circuit (170) contains inhibit signal resistor (171) (3.9 K) and biasing zener diode (172) (5.0 volts). Inhibit filtering capacitor (173) (1.0 nanofarad) and inhibit signal pull up resistor (174) (6.8 K) complete inhibit circuit (170). PWM IC (132) becomes inhibited when the voltage at connection (114) becomes greater than or equal to +6 volts DC. An open circuit condition at connection (114) forces this shutdown condition.

Finally, circuit elements (180) and (182) provide an easy means for modifying the circuitry to accept any of a voltage, current, or resistance signal as the throttle position input variable, by selectively closing jumpers (181) or (183).

Reference is now made to Fig. 7 for a detailed description of the primary structural and functional components of the generic device of the present invention. Although a number of specific embodiments of the present invention are described herein for use in conjunction with both low current/voltage and high current/voltage applications, each embodiment shares the same fundamental, structural and functional features that allow it to operate efficiently and effectively as described. Fig. 7 discloses and describes these specific common structural and functional elements.

The centerpiece of the apparatus of the present invention is an arrangement of MOSFET arrays (200) and the manner in which they are structurally and electrically connected to the DC power source and the DC motor circuit. MOSFET arrays (200) are structurally mounted to and are in thermal contact with heat sink (202). Heat sink (202) is in thermal contact with forced air conduit (204), which, as described in more detail below, is an optional element for high voltage applications that operates in conjunction with standard forced air fans and the like.

The circuitry structure of the present invention involves four primary buss bars arranged to conduct current and to operate MOSFET arrays (200). MOSFET arrays (200) are controlled by way of gate buss bar (208) which itself operates according to control circuitry (218) as described in more detail above and below, which in turn is operated by a variable position throttle device (220). Gate buss bar (208) effectively switches MOSFET arrays (200) on and off according to the pulsed wave form generated by control circuitry (218).

Current flow through MOSFET arrays (200) is by way of source buss bar (210) and drain buss bar (206). Drain buss bar (206) is electrically connected to battery (216), while source buss bar (210) is electrically connected to DC motor (214). The circuit is completed by way of B+ buss bar (212) shown as it is connected between battery (216) and DC motor (214).

An array of filtering/storage capacitors (222) is placed across battery (216) by way of connection to drain buss bar (206) and B+ buss bar (212). Similarly, freewheeling rectifier assembly (224) is connected across DC motor (214) by way of attachment to source buss bar (210) and B+ buss bar (212).

Fig. 7 emphasizes the important feature of the direct connection between MOSFET arrays (200) and buss bars (210) and (206) in particular. In many other attempts to incorporate MOSFET or the like devices in conjunction with DC motor control circuitry, intermediate

current conductors between the solid state devices and the external battery and motor have been the source of frequent failures related to thermal breakdown. The unique placement of MOSFET arrays (200) in direct contact with source and drain buss bars (210) and (206), along with the direct structural mounting of MOSFET arrays (200) on heat sink (202) creates the necessary electrical and thermal environment for the efficient operation of the switching devices.

Reference is now made to Fig. 8 for a detailed description of a second preferred embodiment of the present invention appropriate for use in conjunction with higher current, higher voltage applications. Whereas the above-described first embodiment is most appropriate for moderate current applications (36 VDC typically) such as in golf carts and other such motor vehicles, the embodiment disclosed in Fig. 8 is appropriate for use in conjunction with high voltage applications such as 144 volt electric automobile systems. The motor controller device disclosed in Fig. 8 is comprised of six primary elements shown layered as they would be assembled in the present invention. The foundation of the device is comprised of heat sink elements (250) and (252). Heat sink elements (250) and (252) are each machined from single blocks of aluminum stock to form a generally planer base plate with thermal mass risers (256); (258), (260) and (262). It is to these thermal mass risers (256), (258), (260) and (262) that the MOSFET devices are mounted.

Heat-sink elements (250) and (252) are modularized so that additional elements might be added for higher current requirements. In the alternative, for lower current requirements, only one of the heat-sink elements (250) or (252) might be necessary.

As indicated above, thermal mass risers (256), (258), (260) and (262) are Qdesigned to retain a plurality of MOSFET devices in parallel arrays (264), (266), (268) and (270). In the preferred embodiment of the present invention shown in Fig. 8, there are a total of eight such MOSFET arrays, each comprised of up to eight individual MOSFET devices and positioned in parallel arrangement appropriate for connection to the buss bars in the manner described below. The manner for mounting the MOSFET devices to the thermal mass risers is also described in more detail below.

The structure of heat-sink elements (250) and (252) is such that when they are abutted next to each other, an open area between risers (256, 260) and between (258, 262) is created. This open area (254) is appropriate to retain free-wheeling rectifier assembly (274). Adjacent this open area (254) on one of the planer surfaces of heat-sink (250) is thermal switch (272) that

acts as a safety cut-off for the circuitry of the present invention should the temperature of the heat-sink system go out of range.

Free-wheeling rectifier assembly (274) serves to protect the DC motor and is positioned on the assembly appropriate for cross-connection between the source buss bar and the B + buss bar (see Fig. 7). Free-wheeling rectifier assembly (274) is constructed of copper plate heat-sink (276), which is laid over with a THERMOSIL insulation pad (278) on which are mounted an array of free-wheeling rectifier devices (280) (18 at 50 amp each in the preferred embodiment). Positioned atop devices (280) are rectifier buss bars (282) and (284), each with terminal connections as indicated.

When positioned in open space (254) on heat-sink elements (250) and (252), freewheeling rectifier assembly (274) has a low profile below the level of risers (256), (258), (260), and (262). This permits the subsequent placement of the lengthwise buss bars as described below in more detail.

Mounted along the top surfaces of risers (256), (258), (260), and (262) are three buss bar arrangements. The first arrangement is drain buss bar (294) which is comprised of two rigid copper bars (296) and (298) arranged in parallel configuration across the tops of risers (256) and (260) as well as risers (258) and (262). Copper bar (298) extends beyond the limits of riser (258) as shown so as to provide terminal point (302). Copper bars (296) and (298) are connected by way of flexible braided copper cross-member (300). It is important that cross-member (300) be flexible because of the thermal expansion and contraction characteristics of heat-sink elements (250) and (252). The remaining buss bars described below effectively float atop the drain buss bar (294) and, therefore, do not require the flexible intermediate connection.

A layer of insulating mylar or kevlar sheet (not shown in Fig. 8) is placed between drain buss bar (294) and source buss bar (304). The details of this arrangement are shown and described in more detail below with respect to Figs. 9 and 10. Source buss bar (304) is an "H" -shaped structure with a rigid copper cross-member between two parallel copper bars (306) and (308). Positioned atop each of the four legs of source buss bar (304) are the gate buss bars (310), (312), (314), and (316). As with the separation of source and drain buss bars (294) and (304), gate buss bars (310), (312), (314), and (316) are electrically insulated from source buss bar (304) by way of a thin layer of mylar or kevlar sheet.

Finally, integral to or silver-soldered to drain buss bar (294) is rectifier connector (318). Connector (318) matches up with rectifier buss bar (282) as shown.

Positioned between risers (256) and (258) and between risers (260) and (262), through the gaps arranged in the buss bar assemblies, is an array of filtering/storage capacitors (330). This array of capacitors (330) is mounted to a pair of copper buss bars (326) and (322) which are positioned in parallel arrangement on a 3/16 inch, copper-clad PC board (328). B- buss bar (326) is a narrow copper bar and B + buss bar (322) is a similarly structured copper bar. B + buss bar widens to form terminal (324) at one end. In the preferred embodiment, layers of insulating sheet may be placed between capacitor array (330) and the MOSFET devices mounted to risers (256), (258), (260) and (262). Free-wheeling rectifier strap (288) serves to connect terminal point (332) on B + buss bar (322) with terminal point (286) on rectifier buss bar (284). Appropriate bolts through (286) and terminal (290) make the electrical connection to rectifier assembly (274) while terminal point (332) is silver. soldered to terminal point (292) on rectifier strap (288).

Finally, circuit board (334) is mounted to and positioned atop the entire assembly in a manner that serves as an appropriate means for positioning the low current connections to the MOSFET gates and to the other low current elements of the present device. Each layer of the assembly of the present invention as described in Fig. 8 is attached one to the other either through insulative or conductive adhesives where appropriate, and/or through the use of teflon screws and nuts where insulation is required, or through the use of metallic bolt screws and nuts where conduction is required.

Reference is now made to Fig. 9 for a more detailed description of the method of mounting the MOSFET devices of the present invention to the heat-sink structures. In Fig. 9, heat-sink element (250) (as an example) is shown in perspective detail with one end of riser (256) disclosed. Mounted to riser (256) through holes drilled in riser (256) are MOSFET devices (340), (342), (344), and so on. Mounting screws (346) position and secure MOSFET devices (340), (342), and (344) to riser (256) and ensure good thermal conductivity. Atop riser (256) are positioned drain buss bar (296), insulating mylar or kevlar sheet (360), source buss bar (306), insulating mylar or kevlar layer (362), and gate buss bar (316). MOSFET source lead (348) is shown appropriately positioned and silver-soldered to source buss bar (306), insulated from drain buss bar (296). Likewise, drain lead (350) is shown as it is positioned and silver-soldered to drain buss bar (296). Gate lead (352) is shown positioned and soldered to gate resistor (354) in its connection to gate buss bar (316). Blocking diodes (356) are shown as they are positioned and connected across source lead (348) and gate lead (352).

Reference is now made to Fig. 10 for a detailed description of the specific method for attachment of the MOSFET device terminal leads to the buss bars in the present invention. As shown in Fig. 10, the edge of riser (256) is shown as viewed from the top. MOSFET device (340) is placed and attached to the side of riser (256). Device (340) is positioned such that its three terminal leads (348), (350) and (352) project upward to positions adjacent the buss bars to which they are connected. Specifically, source lead (348) is positioned upward and adjacent to source buss bar (306), drain lead (350) is positioned adjacent drain buss bar (296), and gate lead (352) is positioned appropriate for connection to gate resistor (354) and, therethrough to gate buss bar (316) at solder point (378).

The mechanism for securely and directly attaching MOSFET leads (348) and (350) (the high current conductors) to the respective buss bars is as follows. Three narrow slots (372), (374) and (376) are cut into the edge of each buss bar at positions appropriate for the receipt of the MOSFET terminal leads. The MOSFET lead (348) or (350) is placed within the center slot (374) (as an example in the case of source buss bar (306)), and is crimped within slot (374) by bending the tabs formed from the cutting of slots (372) and (376). Once crimped within slot (374), terminal lead (348) is silver-soldered to provide a secure structural, electrical and thermal contact. A similar attachment is made between drain lead (350) and drain buss bar (296).

Reference is now made to Fig. 11 for a detailed description of the optional forced air assembly of the present invention. In some applications where high currents are anticipated and the temperatures associated with such high currents are anticipated, forced air cooling may be appropriate. The device structure disclosed above with respect to Fig. 8 lends itself to the use of forced air conduits in direct association with heat-sink elements (250) and (252). Positioned below elements (250) and (252) are a plurality of forced air conduits (390). In the preferred embodiment, these forced air conduits are standard, rectangular tube, aluminum stock cut to a length appropriate for the number of heat-sink elements in use. In the embodiment shown in Fig. 11, two such heat-sink elements (250) and (252) are utilized and air conduits (390) extend down the length of both. In the embodiment shown in Fig. 11, an array of eight such square aluminum tubing structures are required.

Forced air conduits (390), each define a cross-sectional air flow (394) that may be larger or smaller according to the thermal requirements of the device. Conduits (390) are positioned and mounted between heat-sink elements (250) and (252) and base plate (392). In the preferred embodiment, base plate (392) is 1/4 inch, sheet stock aluminum, suitable for

mounting the entire apparatus to the body of the vehicle or device whose motor is being controlled. Base plate (392) is of a size sufficient to completely support forced air conduits (390) as well as a plurality of forced air fan devices (396) and (398). In the preferred embodiment, squirrel cage-type fan devices (396) and (398) are utilized and are positioned at one open end of forced air conduits (390). Barriers (402) are open where they are placed adjacent forced air conduits (390) 50 as to permit fans (396) and (398) to either draw out or force in air through the open ends of conduits (390). Power for fans (396) and (398) is provided by way of the DC power supply in standard fashion.

As indicated above, the structure of the present invention is designed to minimize the high current conduction path between the terminals of the device and through the MOSFET elements. The elimination of intermediate printed circuit board or loose wire connections in these high current paths, eliminates much of the possibility for fusible link failures. Likewise, the structure of the present invention is designed to facilitate the versatile arrangement of MOSFET modules on one, two, three or more heat-sink elements. The buss bars described may be configured (lengthened) to accommodate any number of such heat-sink elements along with the associate number of MOSFET devices.

Reference is now made to Figs. 12A and 12B for a brief description of certain modifications to the circuitry described with respect to Fig. 6, appropriate for use in conjunction with a higher voltage/higher current device of the second preferred embodiment of the present invention. PWM IC (432) is a 1524 chip of the type similar to that described in conjunction with the above first embodiment. Biasing of the input of PWM IC (432) is modified as indicated. Resistor (446) (18K), capacitor (447) (3.3 nanofarad), capacitor (442) (0.1 microfarad), and capacitor (440) (0.1 microfarad) serve to configure PWM IC (432) appropriately. Capacitor (448) (0.1 microfarad) appropriately filters the +5 volt reference, and capacitor (461) (0.68 microfarad) and capacitor (463) (100 microfarad), and resistor (460) (10 ohm) function the same as in Fig. 6.

The unique components in Fig. 12A include the input circuitry comprising inductive coil (436) (330 microH), resistor (437) (21.6K), capacitor (434) (0.1 microfarad), capacitor (435) (0.1 microfarad), variable resistor (484) (2-5K) connected at input connector (483), capacitor (485) (0.1 microfarad), diode (487), and jumper (486) function to provide a variable throttle input signal appropriate for use in conjunction with PWM IC (432). Potentiometer (490) fine tunes this input signal.

Circuit element (491) provides an open throttle sense and shut-down circuit and includes transistor (492) (2N4403), resistor (493) (6.8K), capacitor (495) (0.1 microfarad), and resistor (494) (4.7K). THIS open throttle sense and shut-down circuit drives reed switch (499) through resistor (496) (390 ohm) protected by diode (498). Reed switch (499) in its normally closed position is connected to the shut-down terminal of PWM IC (432) by way of a 2.2K resistor. LED (501) is driven by the +5 volt reference when reed switch (499) is in its normally open position. Likewise, wlien reed switch (499) is in its normally open position, the +5 volt reference is provided to connection B, which references connection B in Fig. 12B and functions as described in more detail below.

The output of PWM IC (432) functions much in the same way as that described in Fig. 6, with the output going to a number of FET driver modules (465) (Teledyne TCP4421). In the preferred embodiment, IC (465) is one of eight driver modules for the MOSFET devices. FET driver circuit (465) provides an output through a 1 ohm resister at connection A, which connects to the MOSFET devices as described below with respect to Fig. 12B. Power for the circuit shown in Fig. 12A is provided by a 144 VDC to 15 VDC convertor (417). This convertor is powered off of the battery voltage as indicated.

Reference is now made to Fig. 12B for circuit elements related to the control circuitry described in Fig. 12A. MOSFET circuit element (600) is comprised primarily of MOSFET device (601), which in the preferred embodiment is one of 64 such devices. MOSFET device (601) is configured with gate resistor (602) (47 ohm) and diode (603). The gate of MOSFET device (601) is controlled by way of connector A from the circuit in Fig. 12A through a four-pole two double-throw relay that connects the gate to ground in the normally closed, power off condition. This prevents damage to the MOSFET devices in the power off condition. Reed switch (611) is, as indicated, one of four present in a four-pole, two double-throw relay (610). The control of relay switch (610) is affected by way of connector B from the circuit in Fig. 12A, through the Darlington transistor (604), which in the preferred embodiment is an MPSU4S Darlington transistor. The configuration and biasing of Darlington transistor (604) within circuit (605) is well-known in the art.

Also shown in Fig. 12B is the arrangement of battery (625) in conjunction with B + buss (624) and B- buss (622). Also shown is motor (620) in conjunction with M-buss (626). Between M- buss (626) and the source buss (629) is fast recovery diode (628) which is one often in the preferred embodiment. Between B + buss (624) and M-buss (626) is fast recovery diode (631) which is one of eighteen in the preferred embodiment. Between source buss (629)

and B- buss (622) is shunt (630) used as a current sense location for the circuit. Low pass filter transformer (635) provides a high side and low side current sense by way of connectors C and D tied to PWM IC (432) in Fig. 12A. Common mode protection diodes (640) are provided to the current sense circuitry Of course, in these and other embodiments, the current cal'rying bar(s) may comprise conventional solid copper bars, but also may alternatively comprise other materials including copper or silver alloys, and may comprise braided or other "wires" which are of sufficient current carrying capability to be considered current carrying bars.

Thus, we have disclosed a power controller for an electric vehicle or other device which includes a plurality of transistors in which at least one type of lead (source, drain or gate) is electrically coupled to a current carrying bar. In preferred aspects all three types of leads may be electrically coupled to current carrying bars, and in particularly preferred aspects, one or more types of leads are directly connected to current carrying bars.

We have also disclosed that in another aspect of the inventive subject matter, the transistors may comprise MOSFETs, and particular are not strictly necessary. For example, early controllers relied upon a vibrator to divide the constant D C current flowing from a battery into pulses, effectively modifying the pulse width (U.S. patent 3,911,341), and later devices incorporated transistors to modulate the pulse width, (U.S. patent 4,217,526). Still later devices incorporated field effect transistors (FETs) to satisfy a similar function, (U.S. patent 4,873,453). Moreover, there are several other known MOSFET circuits besides that described exemplified herein for controlling DC power output, (U.S. patent 4,841,165), and it is contemplated that still other types of transistors and circuits will be developed which can be utilized with the inventive concepts herein.

In another, potentially independent aspect of the inventive subject matter, the transistors need not be driven by a pulse width modulation circuit (PWM), but may driven in the more general sense by a duty cycle modulator. There are several ways to accomplish this task. In a simple case, an unmodulated pulse train may consist of square waves, in which the pulse width is approximately equal to the pulse displacement width. other unmodulated pulse trains may consist of pulses having triangular, zigzag or other waveforms, and pulse trains are possible in which the pulse width is longer or shorter than the pulse displacement widths. It is also possible to have a a pulse train consisting of equal spaced pulses and displacements, where the amplitude of the pulses vary over time. Another possibility, discussed at length herein, is to provide a pulse train consisting of pulses having varying widths. Each pulse is represented, even though the width of The pulse is reduced to little more than a spike. Yet another possibility is

to have a pulse train consisting of pulses in which the displacements (also called spaces) between the pulses vary in width. Yet another possibility is to provide a pulse train having a constant underlying frequency, in which individual pulses are omitted. For example, a portion of a pulse train may omit one, four or even 10 or more pulses in a row. Other pulse number modulated pulse trains may have other combinations of sequential pulses and omissions, such as one omission for each third pulse, one omission for each fourth pulse, two omissions for each third pulse, and so forth. Yet another possibility is to provide a pulse train in which the pulses have a constant underlying frequency, but the pulse waveforms are varied. For example, the duty cycle in a pulse train having an underlying square waveform may be modified by having some combination of combination square and triangular waves. Of course, other pulse waveform trains may have other combinations of waveforms. All of the above-mentioned forms of pulse modulation accomplish essentially the same result -- namely, altering the total power (current x voltage) delivered to the load.

In yet another aspect of the inventive subject matter, it is contemplated that electric power sources other batteries could be utilized. For example, power directed to a power controller may be derived from a hydrogen cell, a fossil fuel powered generator, or a super capacitor.

Yet another aspect of the inventive subject matter relates to the frequency or frequencies at which the power transistors are operated. It has long been thought that the efficiency at which DC power can be fed to a load through a pulse wave modulation circuit rises as a function of frequency -- but only up to a point. In particular, the inflection point of optimum efficiency was thought to be below about 19,000 Hz, at which point the conversion efficiency is about 85 - 90%. The inventors herein have discovered, however, that with embodiments such as those disclosed herein, additional efficiency can be derived by operating a power controller at about 19,600 Hz, at which point the conversion efficiency has been measured to be over 95%. Thus, quite independently of other inventive aspects disclosed herein, the inventors have discovered that power controllers can operate at frequencies of at least 19,600 Hz and still provide conversion efficiencies of greater than 90%.

Thus, while specific embodiments and applications have been shown and described, it would be apparent to those skilled in the art that many more modifications are possible without departing from the inventive concepts herein. The invention, therefore, is not to be restricted except in the spirit of the appended claims.

CLAIMS

We Claim:

1. A power controller comprising a plurality of transistors having source, drain and gate leads, wherein the transistors collectively gate current flowing between an electric power source and a load, directly and at least one of the source, gate and drain leads is directly connected to a current carrying bar.

2. The power controller of claim 1 wherein the source leads are electrically coupled to a source buss bar, the drain leads are electrically coupled to a drain buss bar, and the gate leads are electrically coupled to a gate buss bar.

3. The power controller of claim I wherein the at least one of the source, gate and drain leads is directly connected to a current carrying bar.

4 The power controller of claim 1 wherein the transistors comprise MOSFETs

5. The power controller of claim I further comprising a duty cycle modulator which drives the transistors.

6. The power controller of claim 5 wherein the duty cycle modulator produces pulses at a frequency of at least 19,600 Hz, and the overall conversion efficiency is at least 90%.

7. The power controller of claim 5 wherein the duty cycle modulator produces pulses having varied pulse widths.

8. The power controller of claim 1 further comprising a forced air conduit in direct thermal contact with the thermal mass and a means for directing forced air through the forced air conduit.

9. The power controller of claim 2 further comprising an array of filtering/storage capacitors connected in parallel between the battery voltage buss bar and the drain buss bar.

10. The power controller of claim 1 wherein the electric power source comprises a battery and the load comprises a DC motor.

11. The power controller of claim 10 further comprising an array of free-wheeling rectifier diodes electrically connected between the battery voltage buss bar and the source buss bar across the DC motor.

12. An electrically powered vehicle comprising:

an electrical power source;

a DC electric motor which acts to propel the vehicle;

a control system having a plurality of transistors having source, drain and gate leads, which collectively gate current flowing between the power source and the DC motor; and

at least one of the source leads, gate leads, and drain leads electrically coupled to a current carrying bar.

13. The vehicle of claim 12 further comprising a Hall Effect throttle position transducer.

14. The vehicle of claim 12 wherein the source leads are electrically coupled to a source buss bar the drain leads are electrically coupled to a drain buss bar, and the gate leads are electrically coupled the gate buss bar.

15. The vehicle of claim 12 wherein the transistors comprise MOSFETs, and further comprising a duty cycle modulator which drives the MOSFETs at a frequency of at least 19,600 Hz, achieving , and an overall conversion efficiency of at least 90%.

16. A power controller comprising a plurality of transistors driven by a duty cycle modulator operating at a frequency of at least 19,600 Hz., and the overall conversion efficiency is at least 90%.

17. The power controller of claim 16 wherein the transistors have source, drain and gate leads, and collectively gate current flowing between an electric power source and a load, and at least two of tire source, gate leads and drain leads is electrically coupled to a current carrying bar.

18. The power controller of claim 17 wherein the source leads are electrically coupled to a source buss bar, the drain leads are electrically coupled to a drain buss bar, and the gate leads are electrically coupled to a gate buss bar.

19. The power controller of claim 18 wherein the transistors comprise MOSFETs

AMENDED CLAIMS

[received by the International Bureau on 08 September 1997 (08.09.97); original claims 1-19 replaced by new claims 1-20 (3 pages)]

1. A motor power controller comprising:

control circuit providing a duty cycle modulated signal; and

an amplifier circuit which receives the modulated signal and produces a driving current which provides power to operate the motor, wherein at least one of the control circuit and the amplifier circuit are carried by a circuit board, and at least a portion of the drive current bypasses the circuit board.

2. The power controller of claim 1 wherein the motor is a DC motor.

3. The power controller of claim 1 wherein the motor is a DC motor which drives an electric vehicle.

4. The power controller of claim 1 wherein the motor is a DC motor which drives an electric vehicle in an automobile.

5. The power controller of claim 1 wherein the control circuit comprises discrete electronic components.

6. The power controller of claim 1 wherein the circuit board comprises a resinous material.

7. The power controller of claim 1 wherein the circuit board comprises a circuit board.

8. The power controller of claim 1 wherein the signal comprises a train of pulses having varied pulse widths.

9. The power controller of claim 1 wherein the signal comprises a train of pulses having varied pulse widths with substantially constant voltage.

10. The power controller of claim 1 wherein the signal comprises a train of pulses having varied pulse widths and a frequency of at least 19,600 Hz.

11. The power controller of claim 1 having an overall conversion efficiency of at least 90%.

12. The power controller of claim 1 having an overall conversion efficiency of at least 90%, wherein the motor is a DC motor, the signal comprises a train of pulses having varied pulse widths.

13. The power controller of claim 1 having an overall conversion efficiency of at least 90%, wherein the motor is a DC motor, the control circuit comprises discrete electronic components.

14. The power controller of claim 12 wherein the train of pulses have a frequency of at least 19,600 Hz.

15. The power controller of any of claims 1-14 wherein the amplifier circuit comprises a discreet high speed switch.

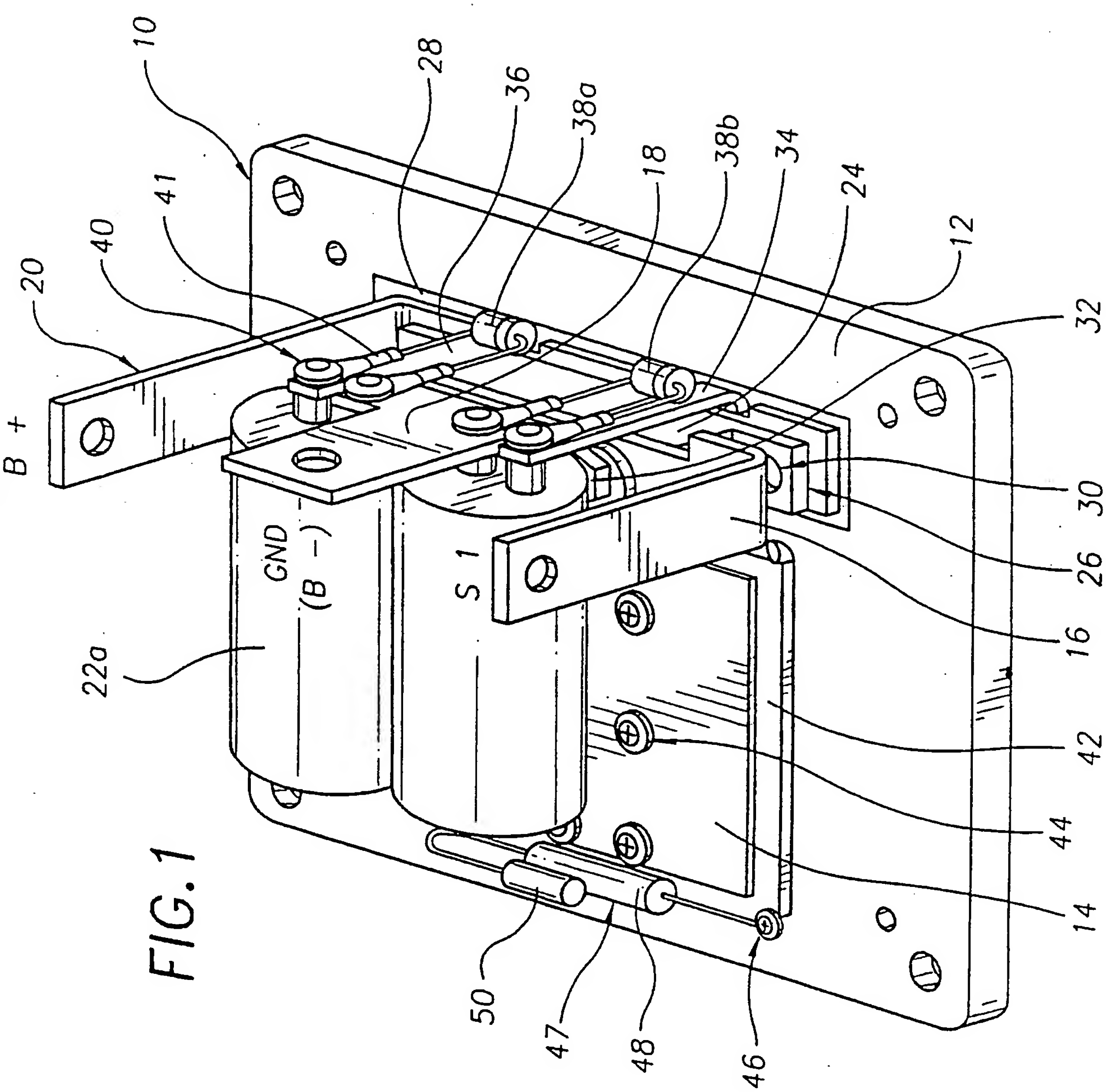
16. The power controller of claim 15 wherein the switch comprises a transistor having a source lead, a gate lead and a drain lead, and least one of the source, gate and drain leads is directly connected to a current carrying bar.

17. The power controller of claim 16 wherein the current carrying bar is physically separated from the circuit board.

18. The power controller of claim 15 wherein the transistor comprises a MOSFET.

19. An electrically powered vehicle comprising the controller of any of claims 1-14, wherein the amplifier circuit comprises a power MOSFET.

20. An electrically powered vehicle comprising the controller of any of claims 1-14, wherein the amplifier circuit comprises a discreet power MOSFET a source lead, a gate lead and a drain lead, and least one of the source, gate and drain leads is directly connected to a current carrying bar which is physically separated from the circuit board.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28
36
38a
18
38b
34
24
12
32
30
26
16
42
44
14
46
48
47
50
22a
20
40
41
B +
GND
(B −)
S 1

FIG. 1

FIG.2a

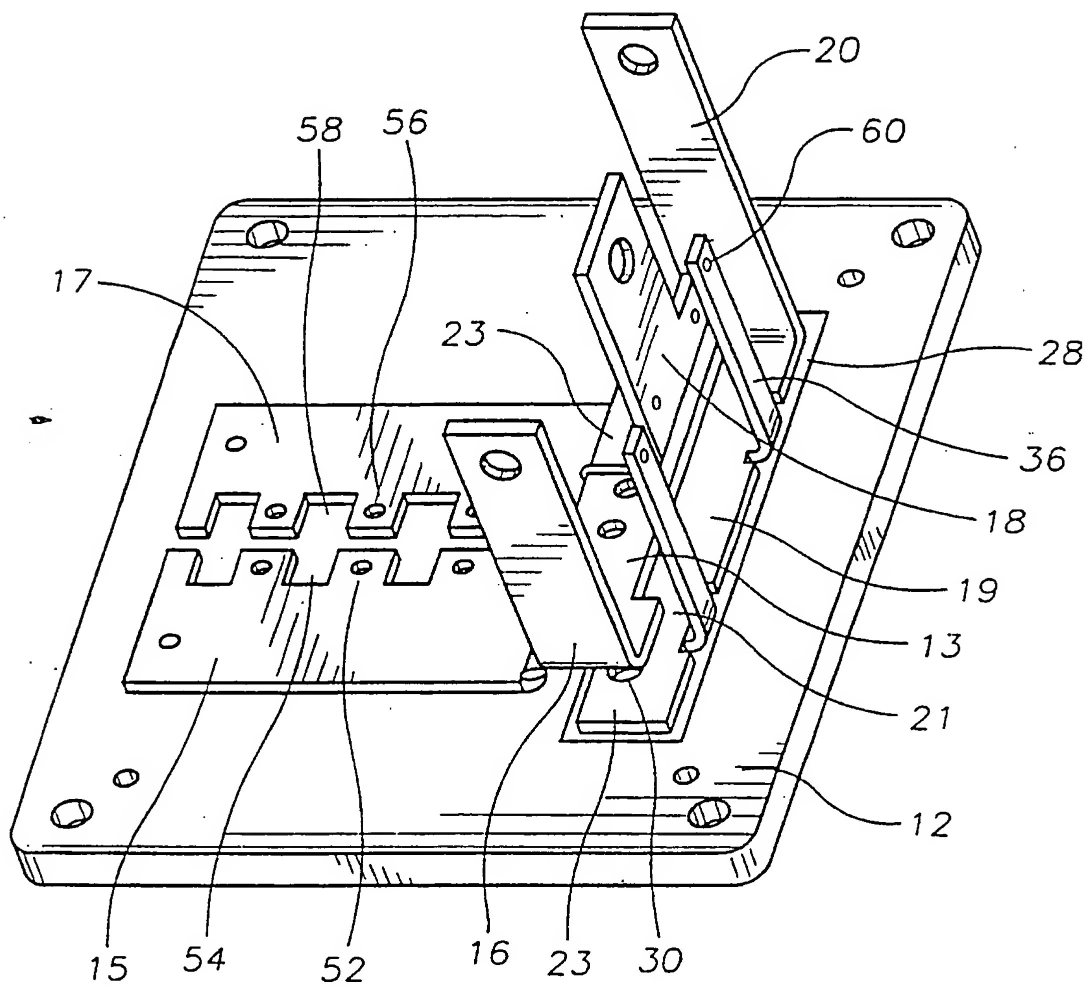
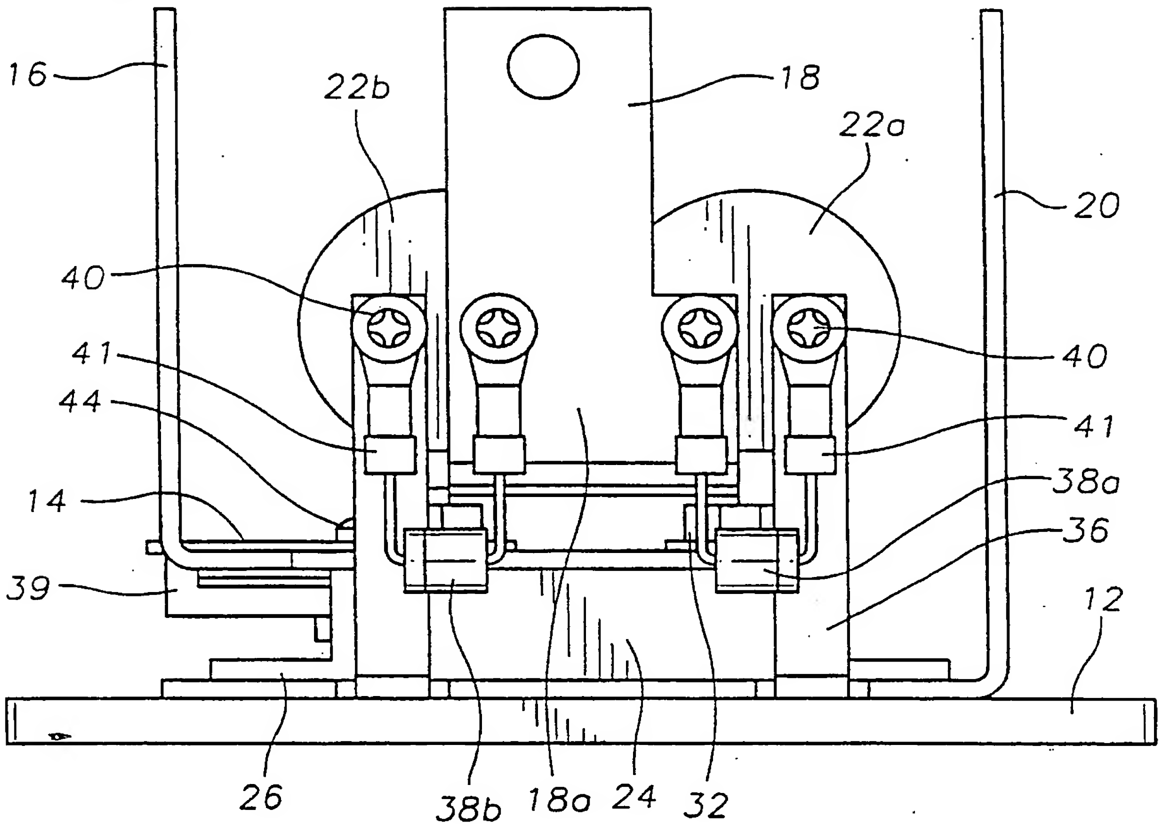


FIG.2b


16
22b
18
22a
20
40
40
41
44
41
14
38a
36
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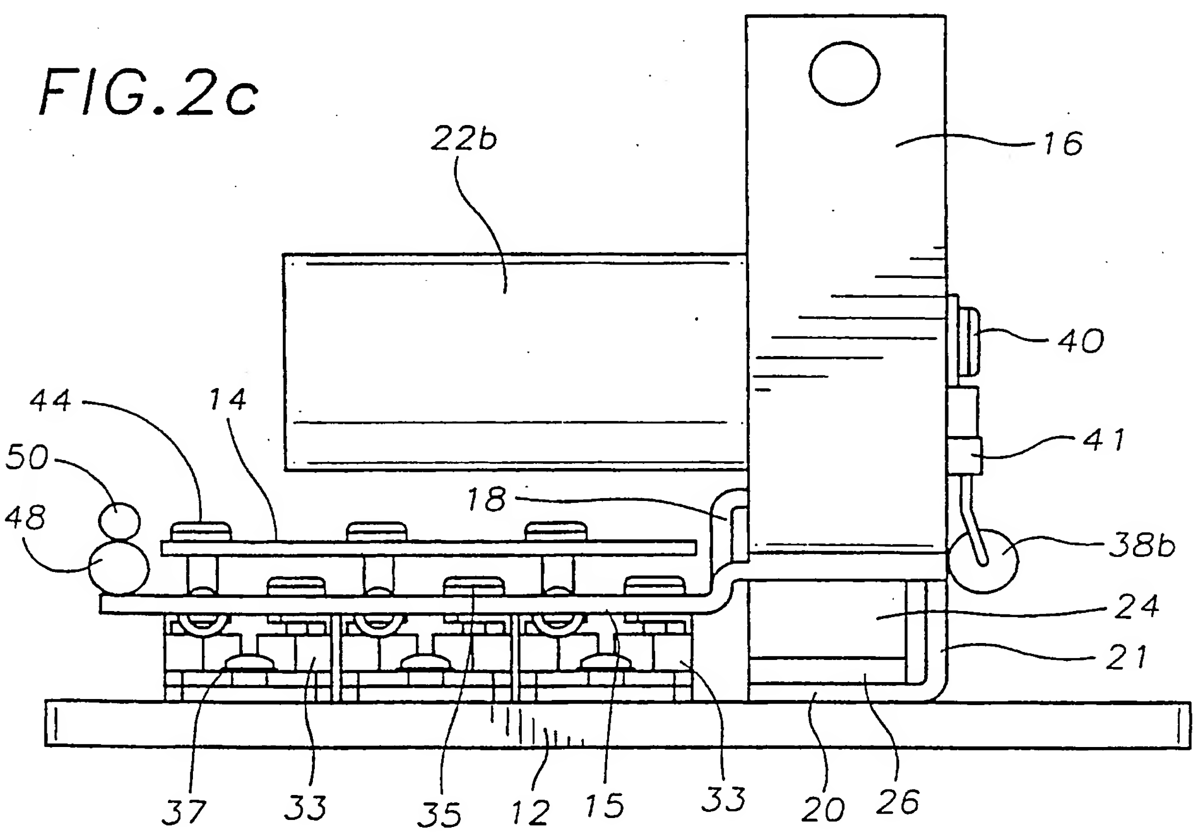
12
26
38b
18a
24
32

FIG.2c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14
50
41
18
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38b
24
21
37
33
35
12
15
33
20
26

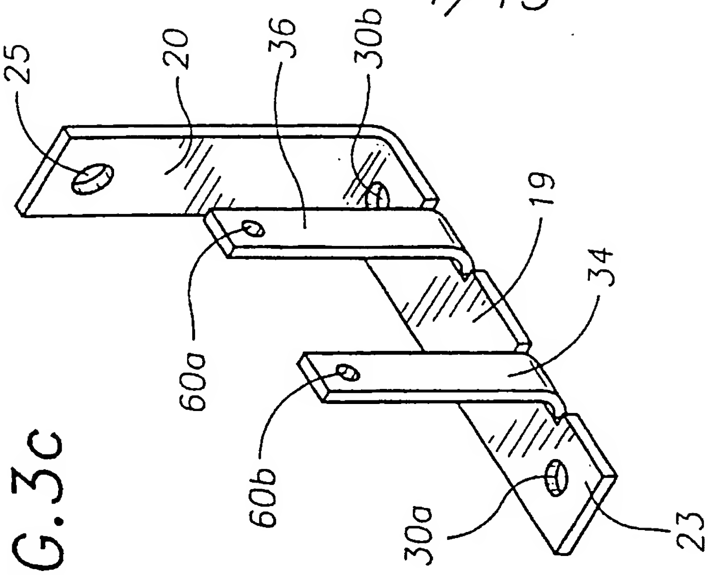


FIG. 3c

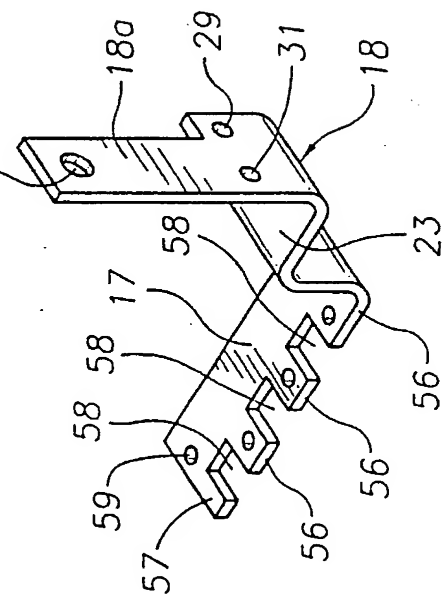


FIG. 3b

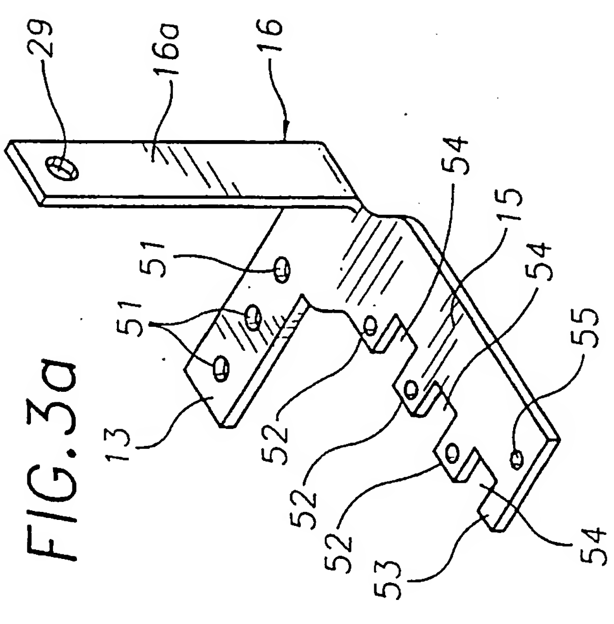


FIG. 3a

FIG. 4

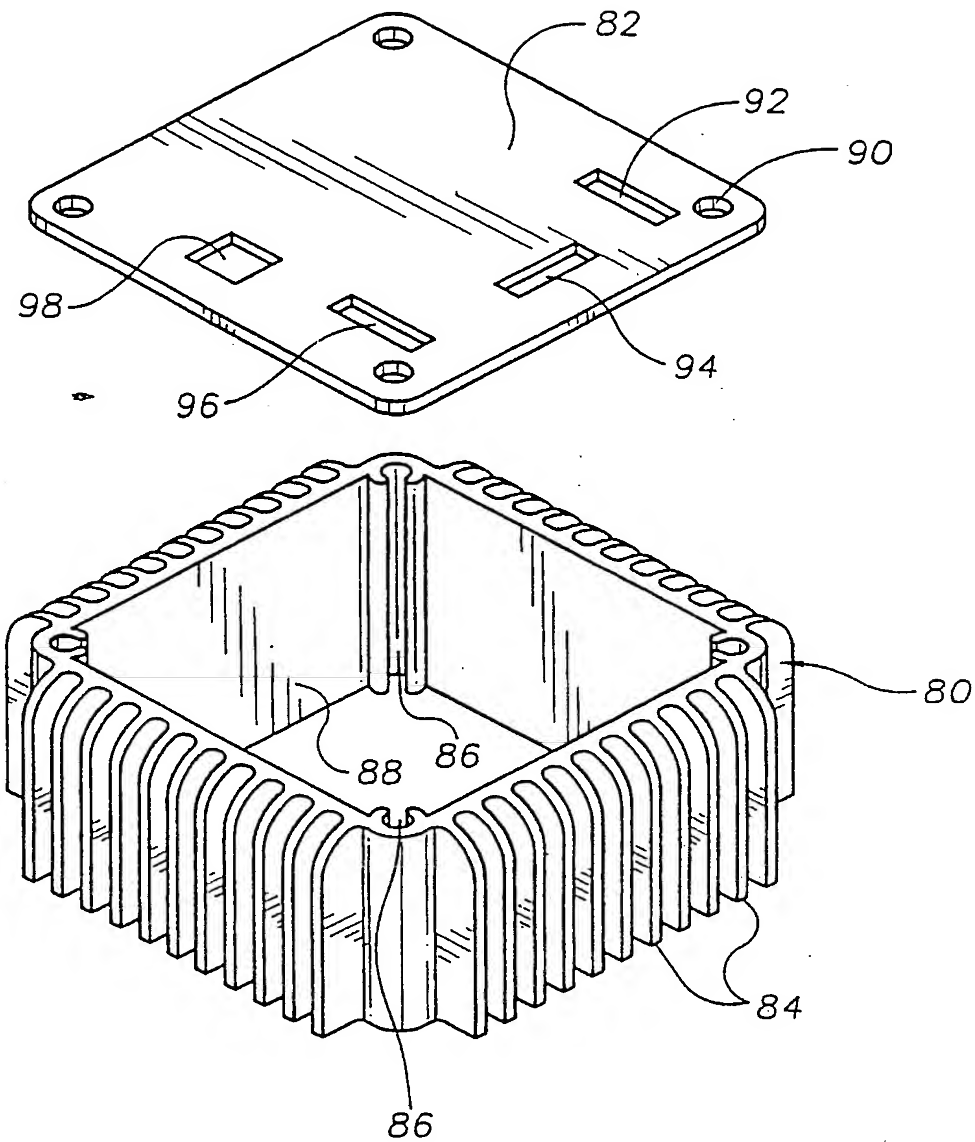
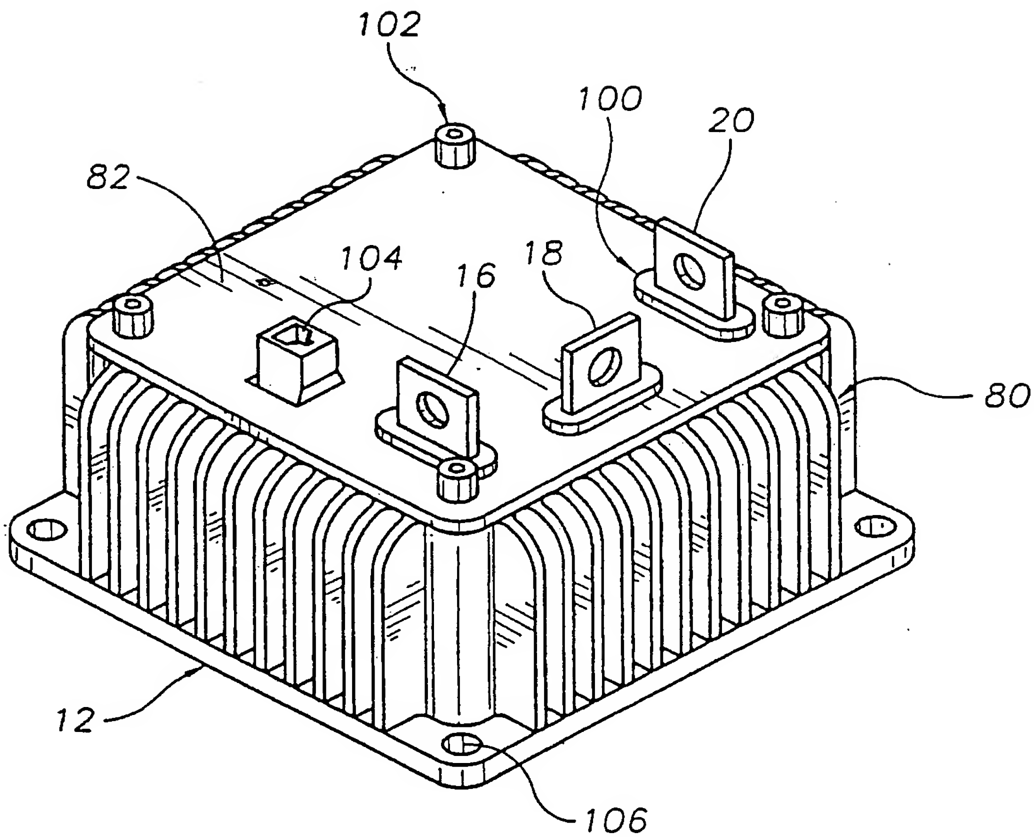


FIG.5



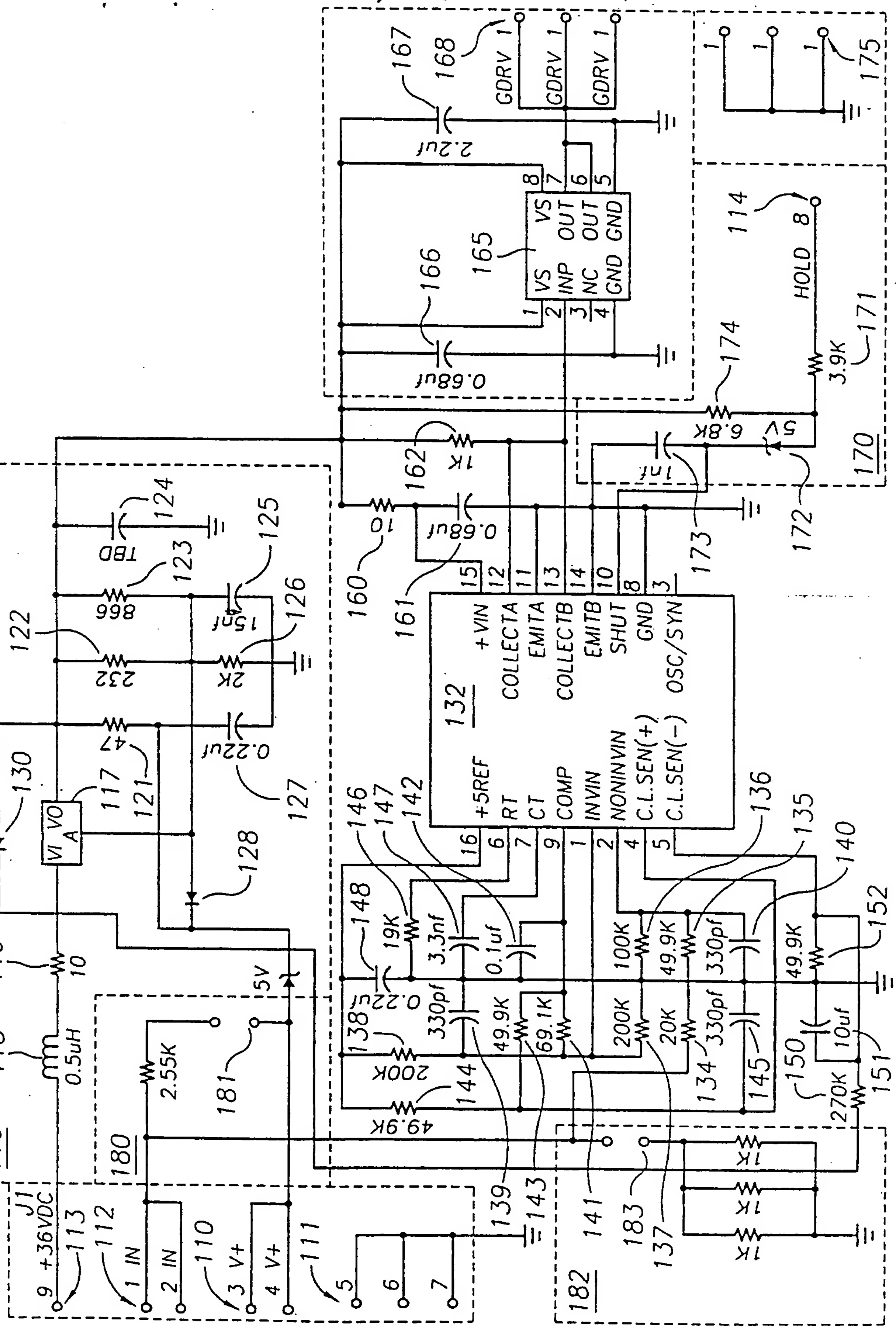

J1
9 +36VDC
1 IN
2 IN
3 V+
4 V+
5
6
7
0.5uH
10
VI VO
A
47
0.22uf
232
2K
866
15nf
TBD
5V
2.55K
+VIN
COLLECTA
EMITA
COLLECTB
EMITB
SHUT
GND
OSC/SYN
+5REF
RT
CT
COMP
INVIN
NONINVIN
C.L.SEN(+)
C.L.SEN(-)
VS
INP
NC
GND
OUT
2.2uf
0.68uf
GDRV 1
HOLD
3.9K
6.8K
1nf
1K
19K
3.3nf
0.1uf
100K
49.9K
330pf
200K
69.1K
20K
10uf
270K
49.9K
1K

FIG. 6

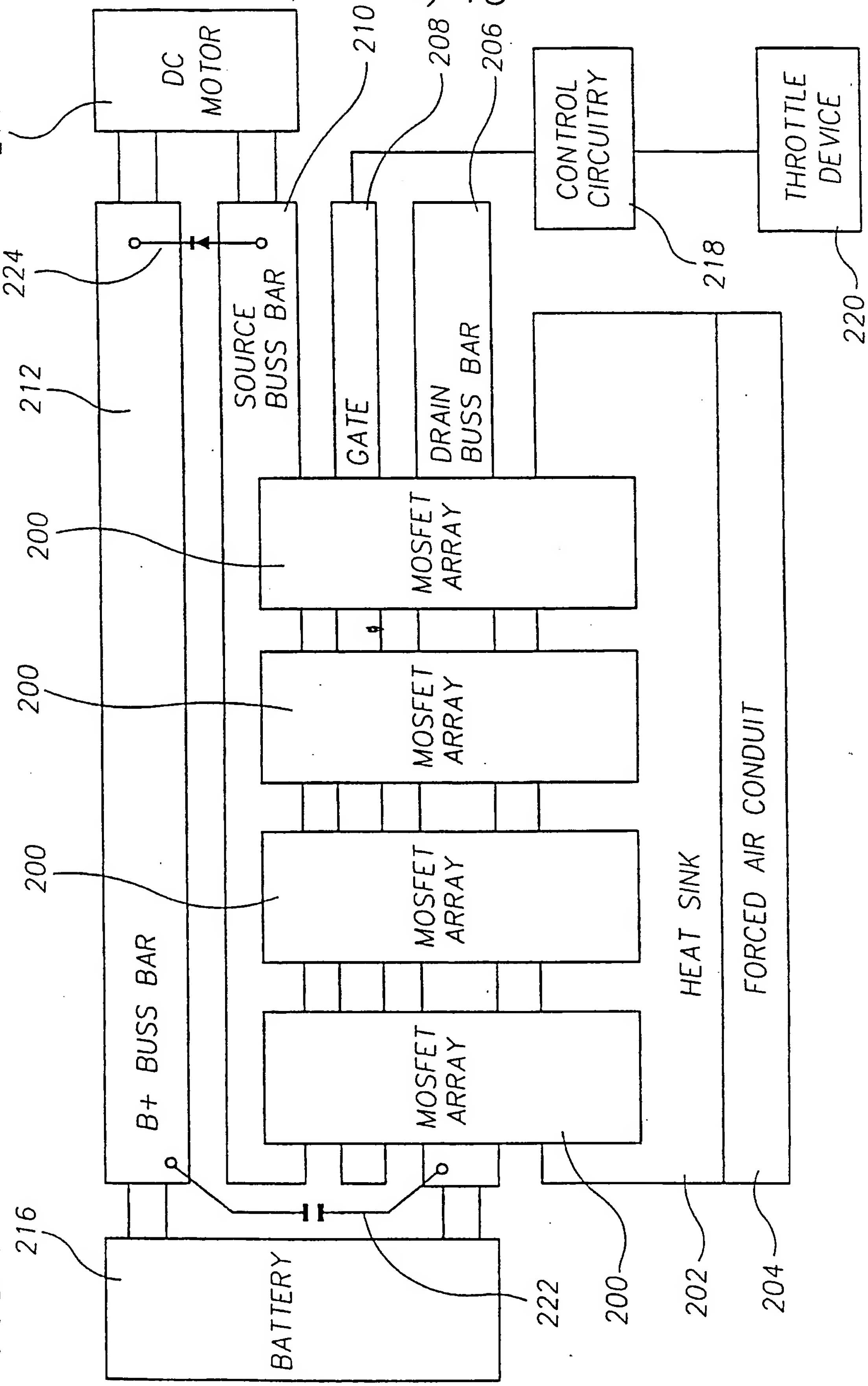
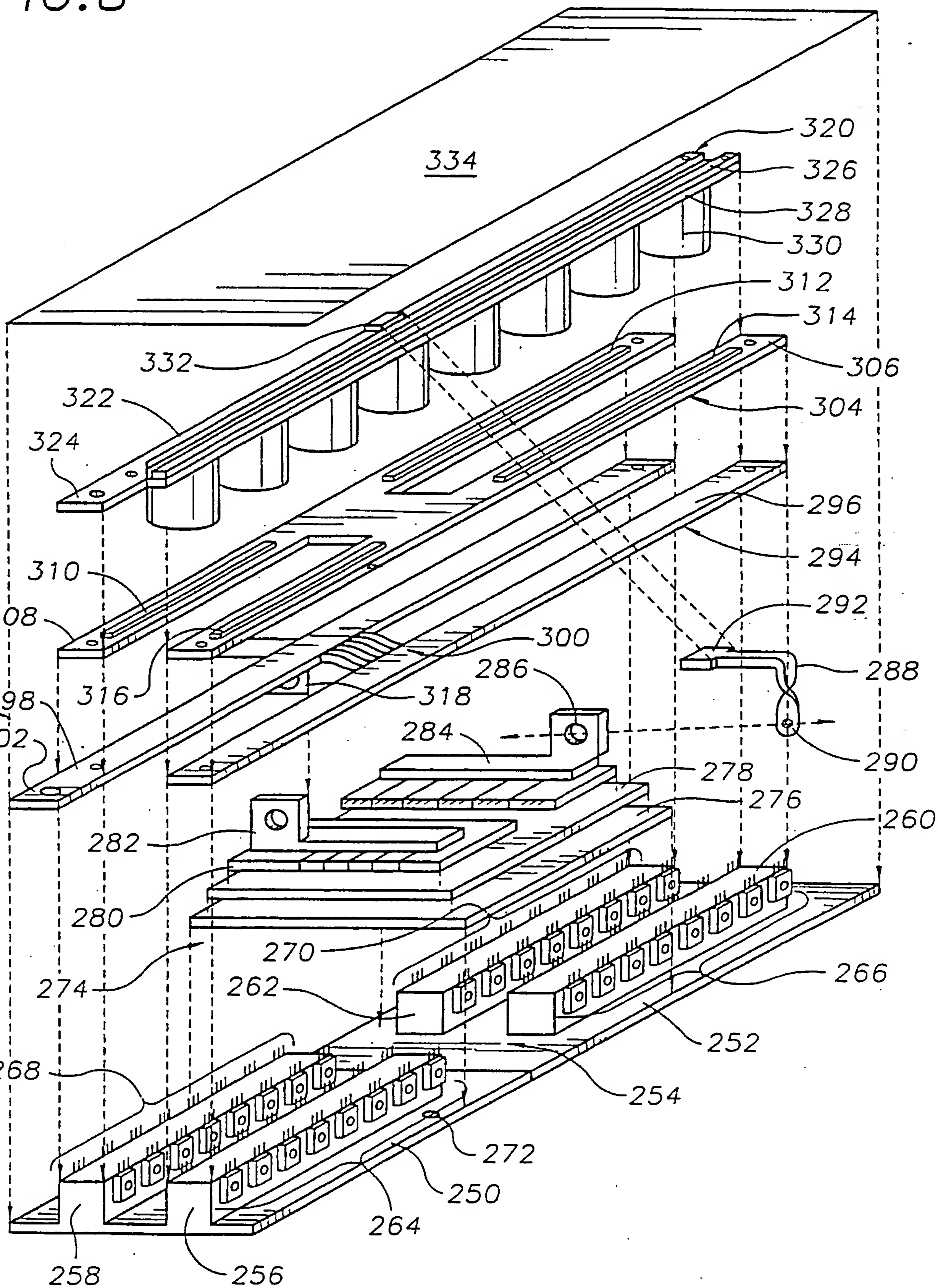

DC MOTOR
214
210
208
206
CONTROL CIRCUITRY
THROTTLE DEVICE
218
220
224
SOURCE BUSS BAR
212
GATE
DRAIN BUSS BAR
200
MOSFET ARRAY
200
MOSFET ARRAY
200
MOSFET ARRAY
HEAT SINK
FORCED AIR CONDUIT
B+ BUSS BAR
MOSFET ARRAY
216
BATTERY
222
200
202
204

FIG. 7

FIG.8



334
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332
322
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316
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298
302
284
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254
272
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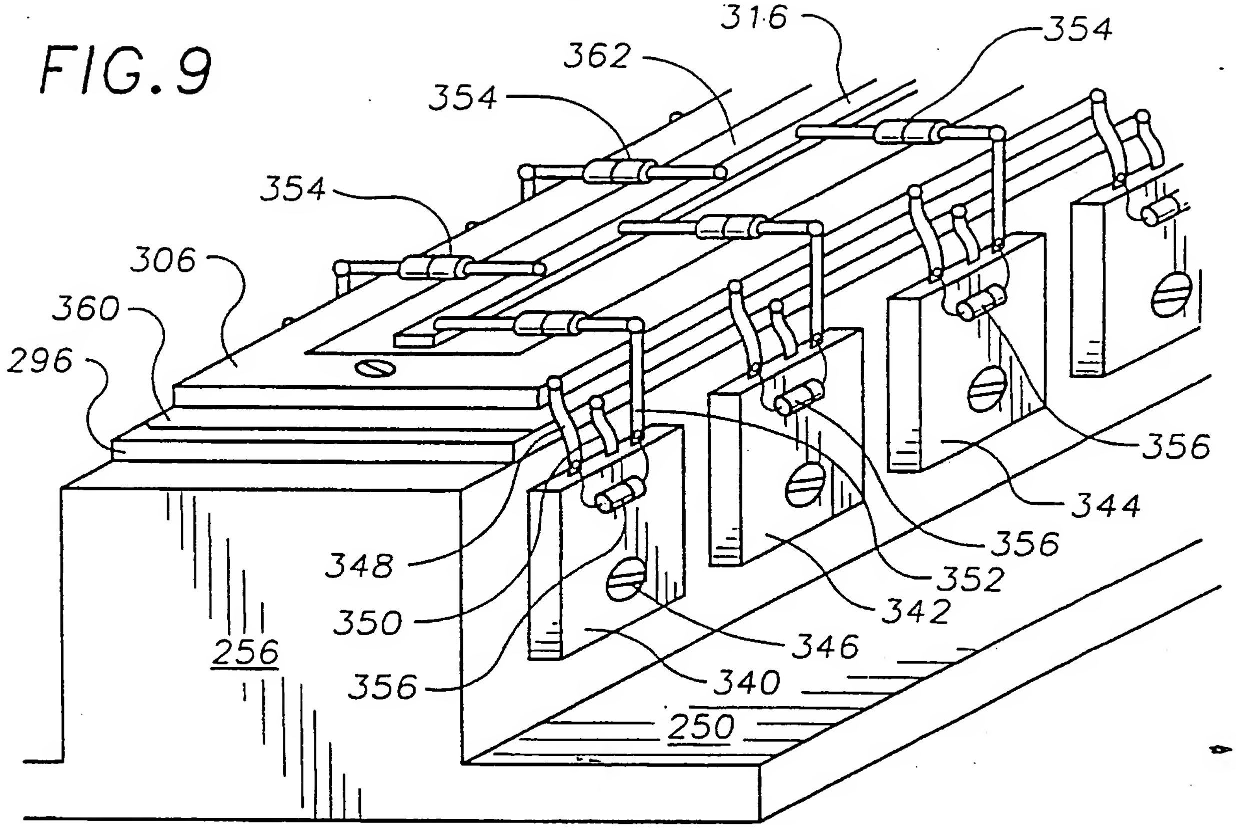
264
258
256

FIG. 9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342
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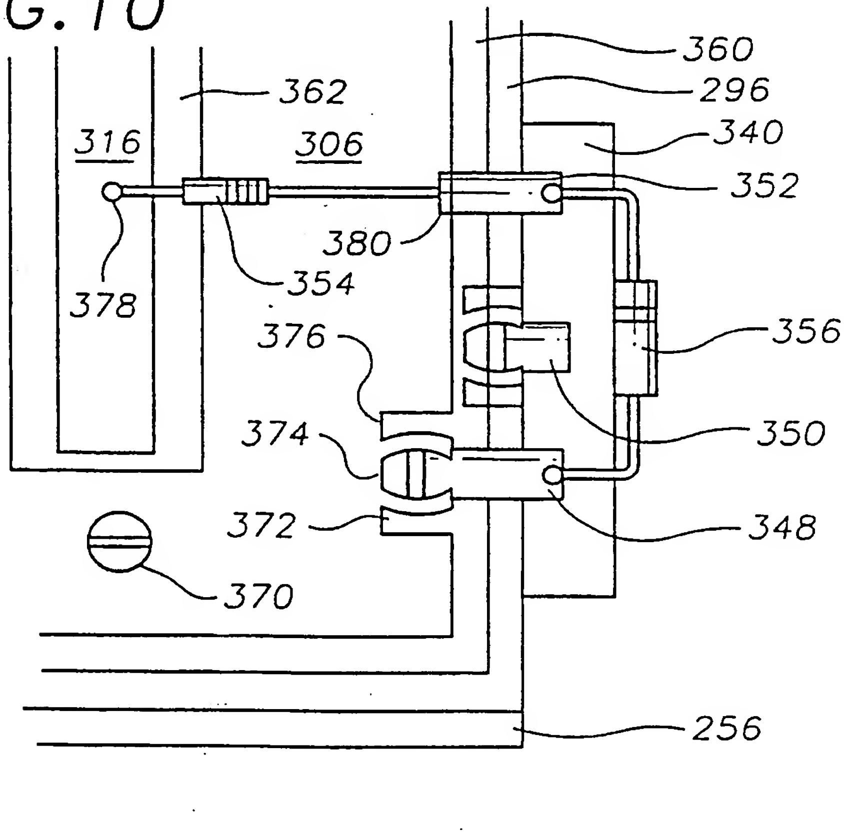
346
356
340
250

FIG. 10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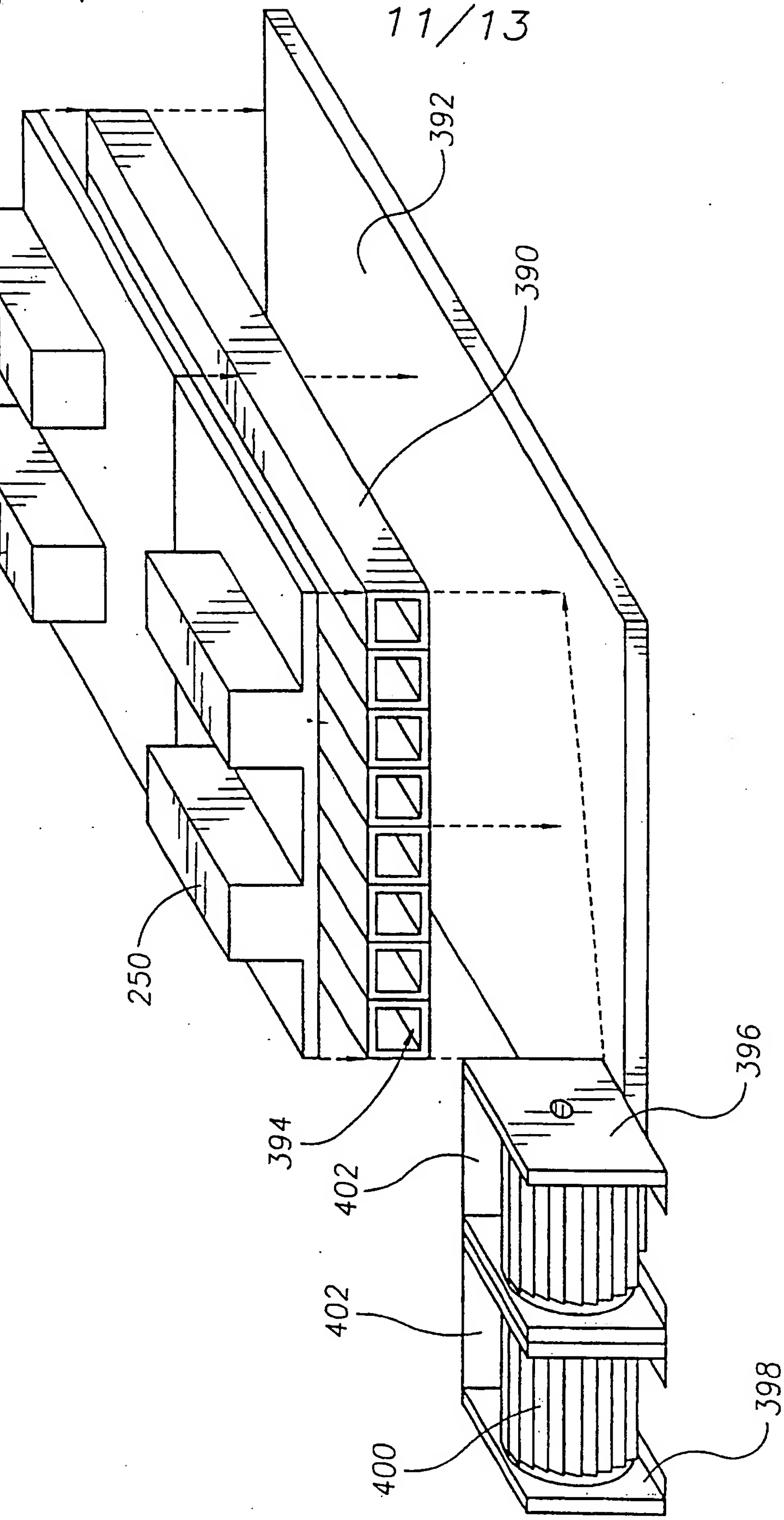


FIG. 11

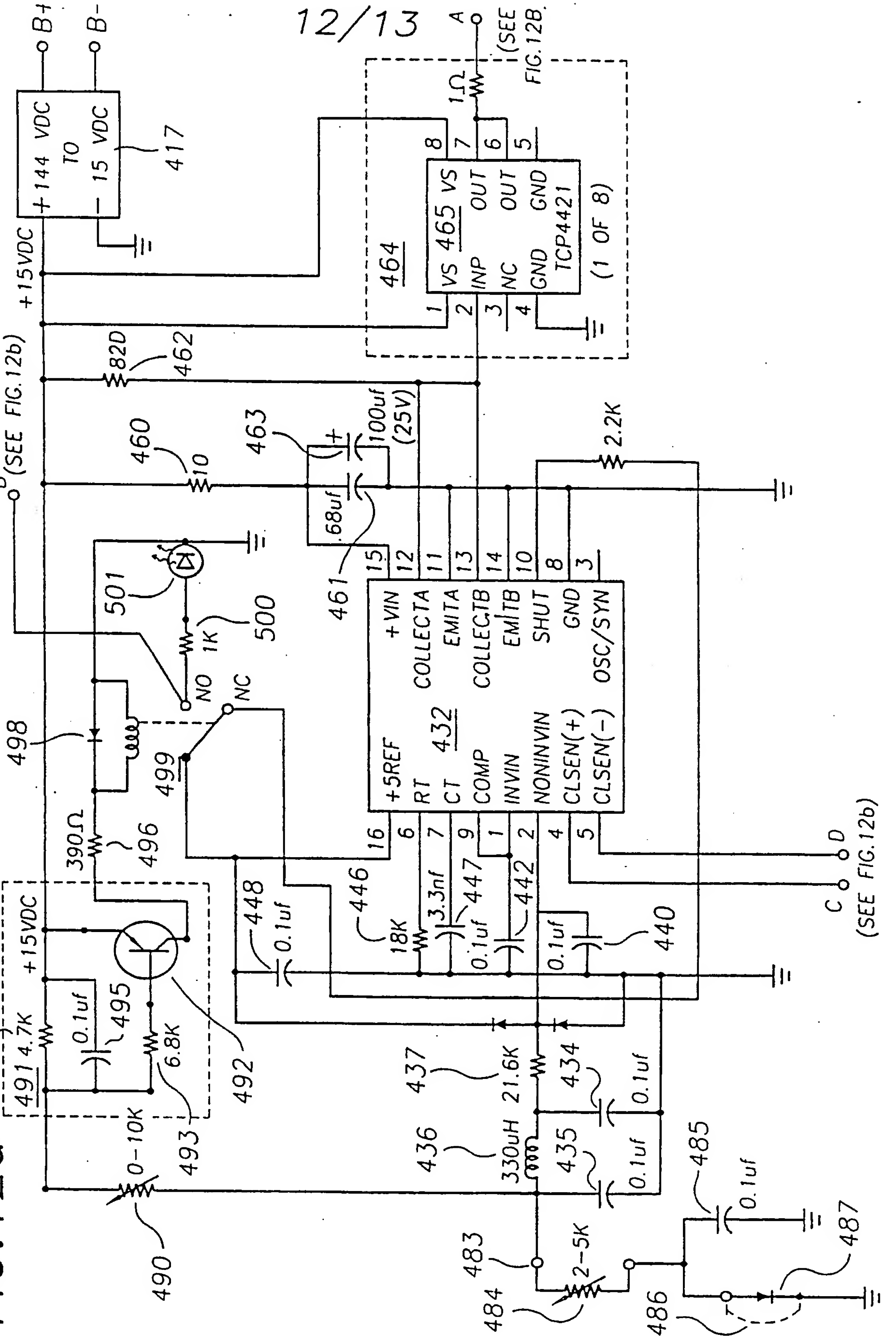
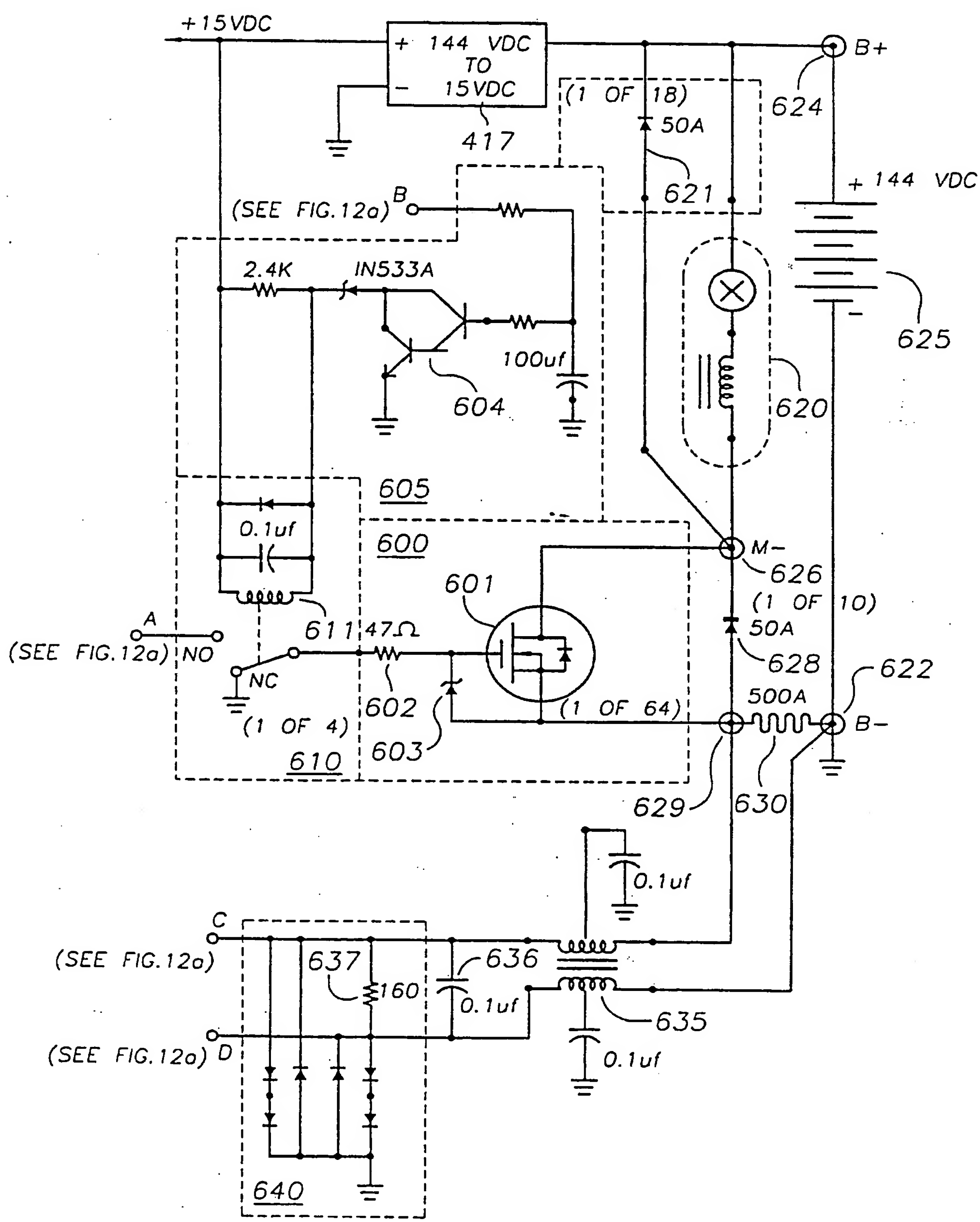

B+
B-
+144 VDC
TO
15 VDC
417
+15VDC
464
VS
465
VS
INP
OUT
NC
OUT
GND
GND
TCP4421
(1 OF 8)
1Ω
A
(SEE FIG.12B
82Ω
462
(SEE FIG.12b)
B
460
10
463
100uf
(25V)
.68uf
461
2.2K
+VIN
COLLECTA
EMITA
COLLECTB
EMITB
SHUT
GND
OSC/SYN
+5REF
RT
CT
432
COMP
INVIN
NONINVIN
CLSEN(+)
CLSEN(-)
501
500
1K
NO
NC
498
499
390Ω
496
446
18K
3.3nf
447
0.1uf
442
0.1uf
440
448
0.1uf
C
D
(SEE FIG.12b)
+15VDC
494
4.7K
0.1uf
495
6.8K
491
493
492
437
21.6K
434
0.1uf
436
330uH
435
0.1uf
0-10K
490
483
2-5K
484
485
0.1uf
486
487

FIG. 12a

FIG. 12b


+15VDC
+ 144 VDC TO 15VDC
−
417
B+
624
(1 OF 18)
50A
621
+ 144 VDC
625
(SEE FIG.12a) B
2.4K
IN533A
100uf
604
620
605
0.1uf
600
601
M−
626
(1 OF 10)
50A
628
A
(SEE FIG.12a) NO
NC
611
47Ω
602
603
(1 OF 4)
610
(1 OF 64)
500A
622
B−
629
630
0.1uf
C
(SEE FIG.12a)
637
160
636
0.1uf
635
(SEE FIG.12a) D
0.1uf
640

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US97/03272

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) : H02P 5/17, 5/168
US CL : 388/811, 815
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 388/811, 815

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5,068,777 A (ITO) 26 NOVEMBER 1991, See entire document.	1-19
X	US 5,089,761 A (NAKAZAWA) 18 FEBRUARY 1992 SEE ENTIRE DOCUMENT	1-19
X	US 5,528,721 (SEARCY ET AL.) 18 JUNE 1996	1-19

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

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"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
03 JUNE 1997	24 JUN 1997

Name and mailing address of the ISA/US	Authorized officer
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